THE ELEMENTS OF
GENERAL ZOOLOGY

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A GUIDE TO THE STUDY OF

ANIMAL BIOLOGY

CORRELATING FUNCTION AND STRUCTURE

WITH NOTES ON

PRACTICAL EXERCISES

BY

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THIRD EDITION

OXFORD UNIVERSITY PRESS
LONDON: HUMPHREY MILFORD

OXFORD
UNIVERSITY PRESS
AMEN HOUSE, E.C. 4
London Edinburgh Glasgow New York
Toronto Melbourne Capetown Bombay
Calcutta Madras
HUMPHREY MILFORD
PUBLISHER TO THE
UNIVERSITY

FIRST EDITION 1927
SECOND EDITION 1928; REPRINTED 1933
THIRD EDITION 1938; REPRINTED 1942

PREFACE

An author who has the temerity to add yet another to the numerous elementary text-books on animal biology must expect the challenge to show cause for his action. In the present instance he would rest his case upon the adoption of a different method of approach to the subject and upon a desire to refute the statement that zoology is a science which does not readily lend itself to experiment. It is unfortunately true that in the past elementary zoology has tended to become too exclusively a study of structure. Relatively little attention has been directed in the handbooks to the functions of the structures so minutely described. The resultant treatment has thus been incomplete and out of touch with the living reality. In this book an attempt at least is made to do justice to function, whilst treating it in close inter-relation with the study of structure.

With the above aim before him, the author had to face the difficulty of keeping the whole work within manageable limits. To economise space in describing structure, the expedient has been adopted of leaving much detail to annotated diagrams. Any disproportion of treatment conditioned by this procedure is compensated for by the more direct appeal of the drawings, which should be used in connection with preparations and dissections.

The natural complement to this study of animal structure in terms of function is the investigation of plant-life. Animal-life and plant-life should form the two interlocking halves of one subject, which under the title of Biology should anticipate the specialisation along one or other of its sub-divisions. This is much more logical, and certainly more practical, than the plan followed in many schools to-day (where the teaching seems too largely a matter of tradition) of commencing with botany.

It must not be thought that the experiments suggested exhaust the possibilities of experiment. Many more will probably suggest themselves. Those included have been collected as on the whole most suitable. Many experiments which might be made have been excluded by the author as unsuitable for an introductory book, and, to a certain extent for economy in space, the common muscle nerve experiments of the University physiology laboratories have been omitted. Excellent small practical handbooks dealing with these are already in existence.

Special attention is called to the practice adopted in the Index of assembling all the references and illustrations concerning a particular type under one suitable heading. It is hoped this will be convenient in the practical classes, where one type will be completely dissected or used for experiment before passing to another.

Many thanks are due to the authors, editors and publishers of the following works for permission to reproduce figures: *Manual of Elementary Zoology*, by L. A. Borradaile (Oxford University Press), for Figs. 7, 8, 17, 32, 53, 83, 95, 96, 191, 225, 228, 234 and 251; *Behaviour of the Lower Organisms*, by H. S. Jennings (Columbia University Press), for Figs. 5 and 6; *Outlines of Evolutionary Biology*, 3rd edition, by A. Dendy (Constable & Co., Ltd.), for Figs. 16 and 101; *Mechanism of Life*, by J. Johnstone (Edward Arnold & Co., Ltd.), for Figs. 42 and 81; *Introduction to Zoology for Medical Students*, by C. H. O'Donoghue (G. Bell & Sons), for Figs. 14, 89, 94, 97 and 249; *Outlines of Chordate Development*, by W. E. Kellicott (Henry Holt & Co., New York), for Fig. 193; *Introduction to Zoology through Nature Study*, 2nd edition, by R. Lulham (Macmillan & Co., Ltd.), for Figs. 15 and 203; *Elements of Animal Biology*, by W. J. Dakin (Macmillan & Co., Ltd.), for Figs. 20, 24, 37, 86 and 205; *Zoology for Medical Students*, by J. Graham Kerr (Macmillan & Co., Ltd.), for Figs. 85 and 118; *Introduction to the Comparative Anatomy of Animals*, by G. C. Bourne (G. Bell & Sons), for Figs. 63 and 132; *Elementary Morphology and Physiology*, by J. H. Woodger (Oxford University Press), for Fig. 84; *Life in*

Ponds and Streams, by W. S. Furneaux (Longmans, Green & Co., Ltd.), for Fig. 213; *Students' Textbook of Zoology*, by A. Sedgwick (George Allen & Unwin, Ltd.), for Fig. 214; *Reptiles, Amphibians and Fishes* (Methuen & Co.), for Fig. 192; *Aquatic Insects*, by Miall (Macmillan & Co.), for Fig. 222; *General Textbook of Entomology*, by A. D. Imms (Methuen & Co., Ltd.), for Figs. 52 and 56; *Elementary Biology*, by G. Parker (Macmillan & Co., Ltd.), for Fig. 245; *Handbuch für Biologische Übungen*, by P. Röseler and H. Lamprecht (Julius Springer) for Figs. 21, 26, 68, 110, 195, 233 and 240-244; Messrs. Baird & Tatlock's General Catalogue, for Fig. 111; Messrs. A. Gallenkamp's General Catalogue, for Fig. 9; and Messrs. Flatters & Garnett's Catalogue of Collecting Material (1924), for Fig. 224; *Ascaris*, by Goldschmidt (Theod. Thomas, Leipzig), for Fig. 46; Minchin's *Protozoa* (Ed. Arnold), for Fig. 4; *Biology of Dragonflies*, by Tillyard (Univ. Press, Cambridge), for Fig. 215; Huxley's *Crayfish* (Kegan Paul, Trench & Co.), for Fig. 190; to L. O. Howard, U.S. Dept. of Agriculture, for permission to reproduce Figs. 186, 33 and 34 from papers by Snodgrass and Casteel, and to Professors M'Gregor and Calkins, for Fig. 174.

My special thanks are due to Miss M. Fordham, M.Sc., to Professor Ramsden, M.A., to Professor Tattersall, D.Sc., to Professor Macdonald, F.R.S., and to Mr. S. T. Burfield, M.A., for their help in reading the manuscript and proofs, and to Miss M. Hamilton, B.Sc., for help in certain preparations.

To the Oxford University Press the author is most grateful for the assistance and courtesy, as well as the care shown in the preparation of the book.

W. J. D.

THE UNIVERSITY
LIVERPOOL
1927

PREFACE TO SECOND EDITION

So short a time has elapsed since the publication of the first edition that only a few changes in the general subject-matter have been necessitated. Two or three illustrations have been changed. The opportunity has, however, been taken of adding a Classification of the Animal Kingdom and of remaking the Index.

The Author would remind the reader that although the plan of the book is 'comparative,' it is intended also as a guide to the study of the usual and common animal types. The Index has been adapted for this purpose.

W. J. D.

LIVERPOOL, *April*, 1928

PREFACE TO THIRD EDITION

TEN years have now elapsed since the first edition of this book was printed. It is very significant that whilst the descriptions of structure may stand with little or no change, almost every story of physiology and function has needed alteration. Numerous small modifications have, we trust, improved the text, and several new additions have been made with illustrations.

The decade which has just passed has produced a new department of biological science in Endocrinology. This is also reflected in a new section.

One of the most marked changes of the same period, at least in the British Empire, has been the serious introduction of Biology into the curriculum of Secondary Schools. This long-delayed advance has resulted in the production of many new elementary books on the subject. We should like to stress the fact again that this text has been written with the aim of encouraging a wider general knowledge of the more important truths of animal biology rather than a crammed encyclopedic memorisation of a few types.

The demand for a third edition and the applications for permission to make use of many of the illustrations encourages a belief that this aim has been to some extent fulfilled.

SYDNEY, 1937

CONTENTS

SECTION II.—THE STUDY OF THE BIOLOGY OF THE MULTICELLULAR ANIMALS

I

INTRODUCTION

FIFTY years ago, before the days of wireless and the cinema, many people made a hobby of natural history. Aquaria were very popular, and so were collections of shells and butterflies. In *Glaucus, or the Wonders of the Sea Shore*, Charles Kingsley, the author of *The Water Babies* and *Westward Ho*, refers to the fact that books of Natural History were finding their way into drawing rooms and school rooms, and that the study itself had become quite an honourable one! Probably if one had asked some of the more enthusiastic naturalists of those days why they were so keen on their collections and their studies, they would have replied that it was the pursuit of knowledge, the understanding of the wonders of this world of ours, and above all the *romance* of investigating 'the marvels of animal life.' Nowadays the amateur naturalist is not so common, and other hobbies have been invented which have their enthusiastic following, but the study of animal and plant biology, which one might almost say has grown out of the natural history of a previous generation, becomes more and more a matter of public interest. The accomplishment of such an engineering feat as the Panama Canal was equally the successful victory over the mosquito and those two diseases, yellow fever and malaria, which had rendered earlier engineering efforts futile. The biological problem really took precedence over the engineering problem.

In every country medical students commence their studies with a course in biology, but this must not be all, for medicine becomes more and more a matter of applied biology, and less a mere study of disease. With more knowledge of the factors, both external and internal, which

control the living organism, we should be able to prevent disease and probably eliminate much of the drug and surgical treatment so common to-day. The teaching of human heredity is only beginning and even since the first edition of this book our knowledge of the so-called ductless glands and of vitamins has completely changed our outlook. Advances in medicine have shown not only that lower forms of animal life play a tremendous part in causing human disease, but also that a study of other animals is essential to a study of man. Much of the essential knowledge referred to above has come from biological studies—the mechanism of heredity has been almost entirely elucidated by experiments on a few kinds of insects and plants.

The great increase in the world's population and the changed and strained habits of civilised society are making various branches of applied biology of great economic importance. The author once commented in Copenhagen upon the remarkable value and the concentrated production of dairy produce, etc., in Denmark. 'Yes,' came the reply, 'but it is not because our country is so specially adapted to it either from the point of view of soil or climate; it is the successful application of science.' Whatever name we like to give it, that science is applied biology.

When the first edition of this book was written there was a danger that the student of animal biology would become a student of dead specimens in a laboratory and confine his studies to structure—the structure of preserved specimens. Fortunately this is no longer the case. The method adopted in this book emphasises function, but it is impossible to study the mechanism of the living animal or its habits and relations to its environment without studying structure as well.

With the exception of the first section of the book, the different chapters deal with those characteristics which are fundamental features of *all* living animals. We might have adopted the more usual plan of devoting a chapter to each animal type considered suitable for elementary study. Such a scheme tends to leave the student with a limited knowledge of a dozen different animals. One misses the great truth that something is characteristic of *all* living

animals, and that this something is achieved in countless different ways.

Over 650,000 different kinds of animals have been named, and no doubt many more species exist. Very little observation is necessary to show that, despite the diversity, all these species fall into a relatively small number of classes. There are striking resemblances between certain animals which enable us to refer to them as belonging to one type. Thus we can recognise fishes, birds, reptiles, insects and so on. If we take all the members of one of these groups and look at them a little more closely, we find that within the group there are smaller classes. Thus, whilst all insects have certain features in common and characters which mark them off from other animals, the group Insecta comprises butterflies, beetles, dragon-flies, cockroaches and so on. All the other big groups of animals present similar relationships. As a matter of fact we may arrange the animal kingdom in a series of groups and sub-groups.

Each kind of animal has a scientific name. Since the time of the Swedish naturalist Linnaeus this consists of two names which are Latin or Greek in form. Thus the domestic cat is *Felis domesticus*, the lion is *Felis leo* and the tiger *Felis tigris*. The common housefly is *Musca domestica* and the English lobster is *Homarus vulgaris*. These names are certainly longer than our common names, but they are not 'inventions of scientists to make their subject appear difficult.' So far as names of animals are concerned, they form an international language. The Japanese student of biology knows exactly what *Felis leo* stands for, and so does the German, the Russian and the Pole. But this is not the only advantage of the system of double names. The first name is known as the generic name and the second as the specific name. Now if we turn back to the cat, tiger and lion, it will be noticed that they all have the same generic name *Felis*. It implies that these three animals have certain characters in common. We believe that they are all related. Thus the name *Felis domesticus* not only stands for the cat which has characters peculiar to itself, but it indicates that the cat belongs to the genus

Felis and is related to other animals having the same generic name. The genus is one of the smallest sub-divisions of our classification.

If we try to sort out the animal groups known to us, we find that on the one hand the **Mammals** (animals which suckle their young with milk—*e.g.* man, monkeys, cats, dogs, elephant, horse, sheep, etc., etc.), the **Birds**, the **Reptiles** (snakes, lizards and crocodiles), **Amphibia** (frogs and newts) and **Fishes** all have a backbone, whilst the other groups of animals (sponges, insects, jellyfish, worms, etc.) lack this structure and other features which go with it. Therefore we group all the backboned animals into a big division called a Phylum, and we name this the **Vertebrata.**[1] Within this phylum we recognise a series of groups called Classes (the Mammals, Birds, Reptiles, Amphibia and Fishes). The cat belongs to the Class Mammalia.

Within the Class Mammalia it is possible to distinguish another series of sub-divisions. The cat, lion, tiger, bear, jackal and others have teeth adapted for a carnivorous diet. They agree in certain structural characters, and may be contrasted as a group to the hoofed animals like the pig, sheep, deer, oxen, etc., which are vegetarian. Both these divisions are known as Orders; the cat and its allies belong to the Order **Carnivora.** Other Orders of the Class Mammalia are the **Ungulata** (hoofed animals), the **Rodentia** (beaver, rats, mice and rabbits), the **Marsupialia** (kangeroos), and others.[2] Further sub-divisions have been made. Thus, in the Order Carnivora certain genera bear greater resemblances to one another, which implies closer relationship. For example, the dogs, wolves and foxes resemble each other more closely than they resemble the cats, and the bears are different from both. These groups form the Families, Felidae, Canidae and the Ursidae. Finally the families are made up of the different genera, each composed of one or more species. We may thus tabulate the position of the Cat as follows:

[1] To be more accurate, we should speak of the Phylum Chordata, which includes the Vertebrata and certain very small groups.

[2] See Classification Appendix, p. 498.

Kingdom - - -	Animal.
Phylum - - -	Chordata.
Class - - -	Mammalia.
Order - - -	Carnivora.
Family - - -	Felidae.
Genus - - -	Felis.
Species - - -	domesticus.

The most important Phyla in the animal kingdom are: (1) **Chordata,** (2) **Arthropoda** (Insects, Crustacea, Millipedes, Spiders and Scorpions), (3) **Annulata** (worms like the earthworm), (4) **Echinodermata** (starfishes and sea-urchins), (5) **Mollusca** (shell-fish like the oyster, cockle, snail, slug and cuttlefish), (6) **Nemathelminthes** (thread-worms), (7) **Platyhelminthes** (flat-worms like the tapeworm), (8) **Coelenterata** (jellyfishes, corals and anemones), (9) **Porifera** (sponges), (10) **Protozoa** (very simple organisms, mainly microscopic, to be described later).

Certain phenomena are characteristic of all living animals, and as it is these fundamental attributes that we are going to stress in studying a representative selection of animals, it will be well to enumerate them. Every animal begins its life as the product of an animal. It may begin as an egg or it may commence its life as some other part of another individual. From this beginning it generally increases in size by **growth,** perhaps undergoes changes in form (like the butterfly, which passes through caterpillar and pupal stages), and then having reached maturity it produces other individuals like itself by some process of **reproduction.** One cannot, however, have life without an expenditure of energy, and this is particularly obvious in the animal world, since animals, in contrast to plants, usually have the power of **Locomotion.** To obtain energy as well as materials to build up the body, animals require food. There are very many ways in which the latter is procured, and elaborate processes, all coming under the head of **Nutrition,** must take place before this food is incorporated into the animal.

An essential to the supply of energy and very closely related to nutrition is that universal function of all living

things—**Respiration.** Respiration is a feature of plants as well as of animals, although more obvious in the latter.

There can be no life without chemical changes; and the production of what we term waste, and waste products must be removed from the animal, otherwise its activity and health would be harmed. The process of waste-removal is termed **Excretion.**

Again, a living animal dependent upon a supply of food and readily affected, for good or evil, by the conditions of its surroundings, must be in 'touch' with its environment. It is characteristic of living substance that it responds to stimuli. In the simplest animals the contact is almost direct. In 'higher' types, however, an elaborate system of sense organs may be developed to receive stimuli from without and also a nervous system to bring about harmony in the responses.

We have enumerated the fundamental functions to be studied in order to acquire a satisfactory knowledge of the animal body and to interpret animal life. It is interesting to see how these same functions are performed by very different animal types inhabiting the world's most diverse environments.

All animals consist of a certain volume and mass of living matter. This living substance (known as **Protoplasm**) is capable of producing different secondary substances and of giving rise to different sorts of structures, and so we find that both internal and external form and structure present endless variety in the animal kingdom. In the human body, for example, there are bones, muscles, nervous tissues in brain and spinal cord, a heart, a liver, lungs, kidneys and so on. The build is complex, and there are many organs.

If we take an animal like the small fresh-water Hydra (Fig. 38), we find no heart or circulatory system, nothing comparable to kidneys, only the rudiments of a nervous system and no special organs of digestion like the liver or pancreas. The structure of this animal is very simple.

If the substance of the Hydra body be examined with a microscope it will be found that it is built up of a large

number of little units called **Cells.** There are only a few kinds of these. In a human being the number of cells is not only exceedingly great (it has been estimated at over 1,000,000,000,000,000) but there is much more diversity of structure. There are, for example, muscle cells forming the muscles, liver cells in the liver, kidney cells, nerve cells, bone cells and many other types. The cells are the units of structure of all living things. Each cell is a little mass of living protoplasm containing a specialised region called the nucleus.

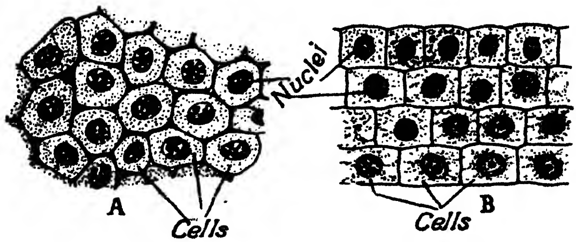


FIG. 1.—Cells in animal and plant tissues.
A. Small piece of skin of young salamander.
B. Part of tissue from root of onion (section).
Note that the fundamental structure of both tissues is the same. Note also connections between cells in *A*.

A detailed description of the cell with notes on some of the more important types is given in Chapter XII. It is necessary, however, to realise at the outset that there is such a unit of living substance.

A brief account of the early discoveries with the microscope which led to the very unfortunate application of the word *cell* (meaning a little chamber or compartment), to the unit of living matter, is given on page 239, and should be read at this stage. The misnomer is easily understood, and soon forgotten, so fixed has the name become. Most cells are microscopic but there are exceptions, the most familiar being animal eggs before they begin their development.

Almost all the larger animals (varying in size from those we can just see with the unaided eye to the largest—the whale) are composed of a number of cells, and they are consequently often termed Multicellular animals or **Metazoa.** There is, however, a most important group of microscopic animals, the **Protozoa,** whose bodies consist of a tiny speck

of protoplasm with no dividing cell walls and usually one nucleus. It is still customary to regard most of them as consisting of only a single cell.

(Those with several nuclei are more difficult to define but are easily recognisable as different from the more complex Metazoa.)

All these independent living cells possess the same fundamental characters as the larger and more familiar multicellular animals. They respire, grow, feed and excrete, respond to stimuli and reproduce their kind. In fact, if conditions be favourable, the protozoa can increase very rapidly in numbers like most small creatures.

We shall begin our studies with a number of examples of these simple animals. It will be seen that we are taking the protozoan types in a rather different manner from the rest of the animal kingdom. Although this inconsistency may tend to accentuate the difference between the protozoa and the multicellular animals, it seems to be necessary in the present state of our knowledge. The student is advised to look back on this section after reading and conducting practical work on other types.

SECTION I

AN INTRODUCTION TO THE PROTOZOA

II

AN INTRODUCTION TO THE PHYLUM PROTOZOA

SINCE the Protozoa are the 'lowest' and simplest of all animals it would appear natural to commence a study of animal biology with this group. Sometimes, however, one of the higher animals such as the frog is chosen because the student is supposed to be more familiar with its structure. Another reason is that the largest species of Protozoa are only about the size of a pin head, and consequently a microscope is necessary in all cases for a study of these animals. However, the types chosen here for illustration and experiment do not require a high magnification. They are of common occurrence and easily obtained. The use of a microscope is necessary sooner or later in biological studies, and therefore there is no reason why the student should not become familiar with it at the outset.

There is more to be said for the practice of passing over the Protozoa at first because of their unfamiliarity to the beginner. It *is* a surprise to see for the first time a transparent and almost structureless *Amoeba* moving about, capturing food and performing the functions which are relegated to special organs in the higher animals.

Taking everything into consideration, however, the writer believes that the 'difficulty' has been overestimated. The first example to be studied is

AMOEBA

The known species of *Amoebae* inhabit the most diverse situations. Most are found in fresh water, some in the sea. They are found in the mud at the bottom or creeping on the surface of the mud. Some inhabit very foul waters. **Where Amoeba live**

Other species live in damp sand, in the soil and in moss. Quite a number are parasites, that is, they live within other animals and at their expense.

Perhaps the best situation to explore for *Amoeba* is the surface of the muddy bottom of small ponds or ditches. A little of the mud should be scraped up and brought to the laboratory with some of the pond water. It should be placed in flat dishes and carefully examined under a microscope.

Cultures

Cultures of *Amoeba* should be made for examination. They can be easily set up by putting about eight seeds of wheat or rice in 150 c.cs. of cold tap water and raising to boiling point for ten minutes. Allow to stand 24 hours before using. Inoculate with *Amoebae*. It is preferable on the first occasion to inoculate with as many individuals as possible, and also to add some of the water in which they were found. Probably many of the animals will die, but some should flourish and reproduce. Once the culture is set going it should be kept up by sub-culturing every three to eight weeks. This simply means introducing a few of the *Amoebae* into a freshly prepared culture fluid. In winter the jars should be kept in a warm place near a radiator or hot pipes.

General features

Amoeba is a tiny organism, large specimens of which may attain a diameter of half a millimetre. It can just be seen, therefore, with the naked eye. Under the microscope it appears to be an irregularly shaped mass of almost transparent granular matter. But a few seconds' observation shows that the shape is constantly changing, and that the substance of the *Amoeba* is flowing out into processes at one point or another whilst others are withdrawn. The processes are termed **Pseudopodia**. Careful watching will show that by this streaming of its substance the *Amoeba* is slowly changing its position. The marginal protoplasm is more free from granules than the central part, and is known as **Ectoplasm**. The more internal granular part is **Endoplasm**. Within this one usually finds small bodies of various kinds (other organisms or parts of such), each enclosed in a film of water. The space in the protoplasm

thus formed is known as a **Food Vacuole** (see Fig. 2). (The term vacuole is commonly used for a space in the protoplasm filled with fluid or gas.)

At one point (generally opposite to that of the greatest pseudopodial activity) a space filled with clear fluid may be seen to form gradually and disappear suddenly. The disappearance is brought about by the contraction of the protoplasm, which forces its contents to the exterior. This is the **Contractile Vacuole.** The fluid which it ejects has entered the *Amoeba* from without and is drained from the living protoplasm; it contains waste products.

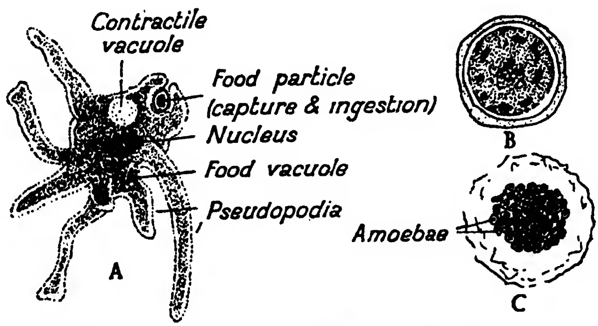


FIG. 2 — *Amoeba.*
A. Amoeba proteus in active movement. *B. Amoeba* encysted.
C. Cyst containing numerous little Amoebae ready to escape. (Modified after Scheel.).

Within the Endoplasm is a more specialised protoplasmic body bounded by a delicate membrane. This is the **Nucleus,** a most essential feature of the organism, and the most important differentiation of the protozoan cell. Without a nucleus a particle of protoplasm may live for a little time, but it is impossible for it to grow or reproduce.

Practical work

I. Observe living *Amoebae* under the microscope and make drawings, illustrating the nature of amoeboid movement. Note the ectoplasm, endoplasm, nucleus and pseudopodia formation (the ectoplasm projects first and the endoplasm streams afterwards). In the endoplasm observe food particles, each with a film of water. Bacteria, small plants and organic particles of various kinds are taken in at any point of the surface of *Amoeba,* the protoplasm

simply flowing round the particle. Food is captured by pseudopodia, and a food particle passes into the endoplasm just as a wet marble sinks into a mass of oil. What is left after the food particle has been acted upon by the living protoplasm is extruded in a similar manner; the *Amoeba* simply flows away from it. This getting rid of undigested food is *not* Excretion, see below.

II. Note the rhythmic appearance and disappearance of the contractile vacuole.

III. Run a little 1% acetic acid in water under the coverslip. The *Amoeba* will be killed, and it will be easier to observe the nucleus.

Nutrition *Amoeba* feeds, in the manner typical of animals, on particles of organic matter, that is, on food which has formed part of the structure of some animal or plant.

This type of Nutrition is called **Holozoic.** In every case the captured food must be changed in character, its complex substance must be altered chemically into simpler compounds before it can be built up and incorporated into the living protoplasm of the *Amoeba.* These processes are **Digestion** and **Assimilation.** Digestion takes place in the food vacuoles, and is the result of the chemical action of digestive juices produced by the protoplasm.

Respiration All animals breathe or respire, a process discussed in detail in Chapter VI. Essentially, this process consists in the passage of oxygen into the animal and its transport to all parts of it. Certain chemical changes (oxidations) result, and in consequence of these a gas, carbon di-oxide, appears as a waste product and is given off. **Respiration** is very simple in *Amoeba.* The whole surface of the animal is in contact with water which must contain some oxygen. This is abstracted and carbon di-oxide is given up. There are no special breathing organs necessary for so simple an organism, and since no part of the cell is really out of touch with the exterior no internal system is necessary to convey either oxygen or any other product through the body. However, since the contractile vacuole indicates that an intermittent current of water is passed out, it is probable that some of the carbon di-oxide escapes by this path.

Excretion Wherever indications of life are present the protoplasm is undergoing changes which result in waste (see chapter on

Excretion). This waste substance in the case of *Amoeba* is collected and extruded by the contractile vacuole, although probably some waste may leave through the general outer surface.

IV. If possible, supply *Amoebae* with bacteria stained with neutral red. (This may be achieved by adding a *very little* neutral red to a hay infusion in which bacteria are living—see *Paramecium* culture directions.) Watch carefully for these coloured bacteria being captured by *Amoeba* and note what happens. The colour of the contents of such a food vacuole changes from red to yellow. The **Practical work (*cont.*)**

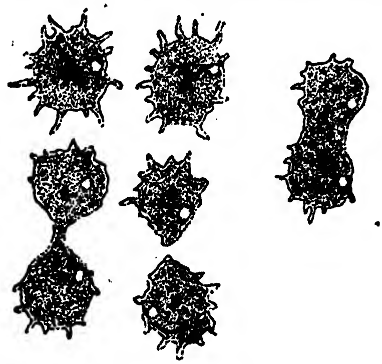


FIG. 3.—*Amoeba* reproducing by simple fission. (After Schulze.)

colour change indicates that the contents of the food vacuoles are at first acid, but later become alkaline. Experiments have shown that the digestion is mainly that of proteins (see page 50), and that whilst carbohydrates may be digested, fats are incapable of digestion.

Reactions of Amoeba to stimuli

V. Dip the tip of a capillary glass rod into powdered methyl green and bring this into a drop of water containing an *Amoeba*. Using the microscope, watch the green dye gradually diffuse until it is seen to make contact with the *Amoeba*. The part stimulated, if moving, comes to a stop and contracts. Pseudopodia are put out at another part and the *Amoeba* moves away. Try 1% solutions of common salt, cane sugar and solutions of HCl varying between ½% and 2%. Note also the effect of touching the *Amoeba* with a fine glass point.

Note the effect of raising the temperature of the slide upon which a drop of *Amoeba*-culture has been placed. Observe also the effect of lowering the temperature. (This can be carried out best with a microscope stage which permits of hot and cold water being passed through it. However, simple direct methods may be devised for the same purpose. A piece of metal plate may be cut to fit on the microscope stage and having a long projecting piece on one side which can be heated with a spirit lamp.) The pseudopodia are withdrawn at high and low temperatures. Note the temperature from which there is no recovery.

Encystment and reproduction

Under normal conditions *Amoebae* reproduce by dividing into two. This process is initiated by the division of the nucleus; the rest of the protoplasm then divides (see Fig. 3). Under certain conditions *Amoeba* withdraws the pseudopodia and forms a protective case or cyst around itself. ~~In this~~ condition (encysted) *Amoebae* may withstand drying or freezing, and may be blown about in dust from one place to another. Distribution may take place in this way. In the encysted stage in some species it has been claimed that the nucleus and protoplasm divide into several pieces, and a number of small *Amoebae* may thus leave the cyst.

Sexual reproduction has, so far, not been shown to take place, and of course different sexes cannot be demonstrated at all.

Summary

Amoeba, whilst only a single cell of the simplest structure, is a typical animal organism performing all the functions characteristic of one of the 'higher' animals. It responds to stimuli, respires, takes in food and digests it, excretes, moves from place to place and reproduces. It is directly comparable, therefore, with one of the multicellular animals in which all these duties are undertaken by specialised cells.

Some kinds of *Amoeba* are to be found living within the bodies of other animals, and certain of these occur in man. Species of *Entamoeba* have no contractile vacuole. *Entamoeba coli* is a harmless occupant of the large intestine and feeds on waste matter and bacteria. The species *Entamoeba histolytica* is, however, a dangerous parasite, destroying living tissue and causing one of the forms of dysentery. It probably enters the body in contaminated food or drink. It passes out in an encysted state, and as it is characteristic of *E. histolytica*

for its nucleus to divide into four whilst in this condition, it is possible to distinguish its cysts from those of *E. coli* which have eight nuclei.

PARAMECIUM

Occurrence and preparation of cultures

Paramecium (of which there are several species) is another Protozoan found almost universally in ponds and ditches. It does not belong to the same class as *Amoeba*, but to a sub-division of the Protozoa known as the **Ciliata.** The group has also been termed Infusoria, because of the frequency with which certain species appear in infusions. If, for example, a little hay is covered with water in a large beaker (the beaker should be placed in a warm spot), and examined from time to time, a succession of different organisms will gradually appear. *Paramecium* may not be obtained in this way unless specimens happen to be in the tap water used. In order to obtain a culture of *Paramecium*, a small quantity of hay should be boiled in water for about one minute. When the infusion has cooled add a little water from a pond or ditch where *Paramecium* probably occurs. Bacteria develop in large numbers and a pellicle forms on the surface. Then various Protozoa appear in succession, and eventually a culture containing *Paramecium* should be obtained. It is advantageous to add one or two very small pieces of the foot or gills of a fresh water mussel (*Anodon*), if such is at hand.

Examine a drop of water from a good culture of *Paramecium* under the microscope. Note the rapid movement of the individuals. They may be better observed if entangled in some fibres of cotton wool. An excellent method for slowing down the *Paramecia* is to add a drop or two of a very thick solution of Carragheen in water to the drops of *Paramecium* culture on the slide.

General description

Compared with *Amoeba*, *Paramecium* has a more definite outer layer (ectoplasm), and this again is differentiated into two layers, the outermost being a firm but thin **pellicle** or **cuticle,** which covers the organism and limits its shape. The shape is like that of a very short cigar; the blunt end progresses first as the animal moves.

No pseudopodia can be protruded owing to the firm nature of the pellicle. The surface is covered with very delicate processes which have the power of making rhythmic waving movements. Such permanent processes of a cell are known as **Cilia.** On *Paramecium* the cilia are arranged

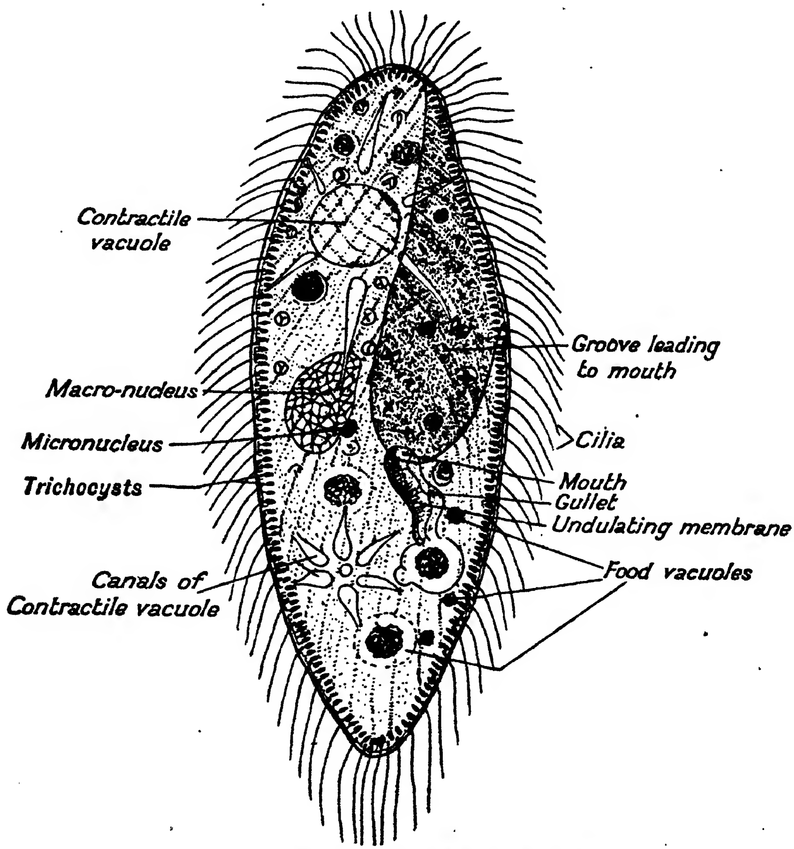


FIG. 4.—*Paramecium.* (From Minchin after Lang.)

in definite rows which run slightly spirally. Consequently by rhythmic movements of the cilia *Paramecium* travels forward, rotating on its long axis like a rifle bullet through the air. Note the action of the cilia. The *Paramecia* may move either forwards or backwards. Their track is not straight but spiral. Note that if the animals strike an obstacle they go backwards for an instant, then turn

slightly sideways and swing again forwards. This sequence is repeated so long as the way is blocked. The same method is used in avoiding other agents. It has been called the *Avoiding Reaction.*

One surface of *Paramecium* is somewhat flattened, and this is termed the **Ventral Surface.** A groove, the **Vestibule,** runs spirally along it, the deepest end being posterior. At this point there is a funnel-shaped depression which runs into the endoplasm. Since food particles are wafted down this depression by the cilia of the groove and by an **undulating membrane** formed of fused cilia, the depression is sometimes very inappropriately called the **Gullet** or **Oesophagus.**

The food particles are forced into the endoplasm, which they enter enclosed in droplets of water (as in *Amoeba*), and so form food vacuoles. In *Paramecium* these food vacuoles are carried round the body owing to a constant streaming of endoplasm (termed Cyclosis). Gradually digestion takes place and a residue of undigested matter is left. This can only be extruded at one place (just as the entrance of food particles was restricted), owing to the firmness of the ectoplasm.

FIG. 5.—Path of moving *Paramecium.* (From Jennings.)
The figures 1, 2, 3, 4, etc. show the successive positions occupied.

A series of extremely minute spindle-shaped bodies—**Trichocysts**—are situated in the ectoplasm just beneath the cuticle and at right angles to

the surface. Under certain circumstances each trichocyst may discharge a minute thread. They have been claimed to be weapons of offence or defence, but recent work shows that they serve more probably for attachment, and that the threads are actually the result of the extrusion of fluid substance.

Within the ectoplasm, but at regular intervals projecting somewhat into the endoplasm, are two **contractile vacuoles,** one near each end. They contract rhythmically. As they

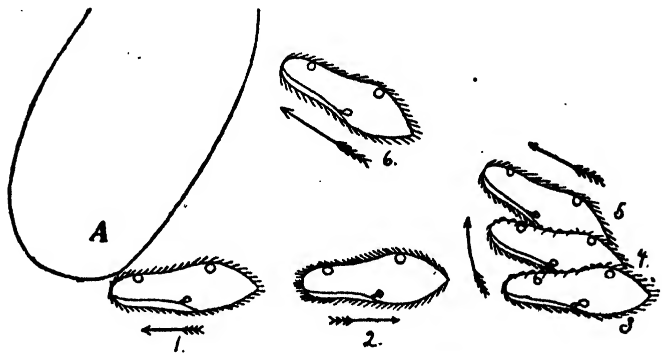


FIG. 6.—Diagram of avoiding reaction of *Paramecium*. (From Jennings.)
A is stimulating object or fluid. 1-6, successive positions occupied by the animal.

enlarge, a number of little **collecting canals** appear converging into each. Fluid is running along these canals into the vacuole.

Deeper within the endoplasm are two nuclei, the smaller one of which is almost embedded in the larger. They are known respectively as the **Micronucleus** and the **Macronucleus** (see Fig. 4). Observation shows that the Micronucleus is concerned in the processes of reproduction. The Macronucleus probably controls the general activities of the living protoplasm.

Respiration and Excretion takes place as in *Amoeba.*

Experiments with Paramecium (Reaction to light)

I. Shade one side of a vessel containing *Paramecium* or direct a beam of light to one side of a drop of culture. There will probably be no effect with ordinary daylight. With light from a mercury lamp, the result will be a definite movement away from the dangerous light which kills

Paramecia exposed to it. However, this reaction to light can be shown with daylight if the *Paramecia* are sensitised like orthochromatic photographic plates by staining them with a little eosin solution. More of the available light energy will then be absorbed. Stain by adding an equal quantity of $\frac{1}{10}$% eosin solution *in water* to a little culture fluid. Divide this into two portions, and set one in the light whilst the other is kept shaded.

II. Place a little culture fluid on a glass slide. Place a drop of $\frac{1}{2}$% salt solution in the centre of the fluid by means of a finely drawn out pipette. The *Paramecia*, **Reaction to chemicals**

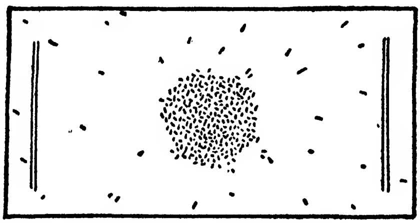


FIG. 7.—*Paramecia* collecting in a drop of $\frac{1}{50}$% acetic acid. (From Jennings.)

which are moving in all directions, exhibit the avoiding reaction as soon as they make contact with the salt solution. The result is that the drop of salt solution remains practically empty.

III. Introduce a drop of $\frac{1}{50}$% acetic acid into a preparation in a similar manner to that described above. The *Paramecia* will collect in the acid. Note how this takes place. The animals enter it by their ordinary movement, but respond with the avoiding reaction when they come to the water again at the other side of the drop. The acid solution acts therefore as a trap. (Note: in experiments with solutions like those suggested above, it is often necessary to try several concentrations of the reagents used. The author has found that cultures react differently in this respect.)

IV. Place a slide, with a quantity of *Paramecium* culture under a large rectangular cover slip supported at the corners by thin pieces of cover glass, over a jug of hot water or on a **Reaction to temperature**

bottle containing water at a temperature of 50° C. Note the increase in the rapidity of movements. When the slide is warmed put a drop of cold water on the upper surface of the cover glass.

Note how the *Paramecia* gradually collect under this by the same process which brought about the collection in the drop of acid. There is no attraction as such, but *Paramecia* which enter the cool region perform the avoiding reaction whenever they touch the warm margin around them, and so are trapped and retained in the cold area.

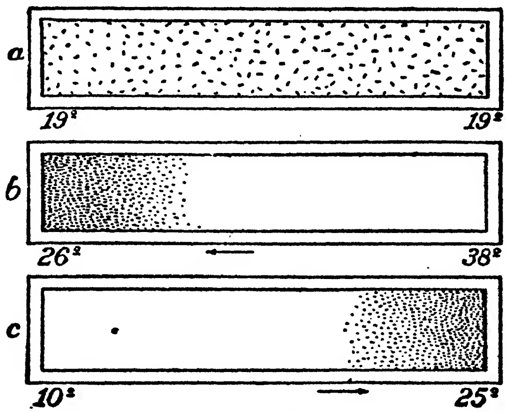


FIG. 8.—*Paramecium*, reactions to temperature differences. (From Jennings.)

V. Make a similar experiment, placing the slide on ice. Note the slowing down of movement. Put a drop of warmed water on the surface of the cover glass and note collecting of *Paramecia* under it.

There is an optimum temperature under which the *Paramecia* tend to collect. This may be found by having a concentrated culture fluid in a flat glass trough, the ends of which can be kept at a different temperature. (Each end may rest on a separate copper plate, which projects outwards and can be heated.) The *Paramecia* will travel from one end to the other according to the temperature. It has been shown that normally they prefer a temperature between 24° and 28° C. (The optimum can be altered by experiment.)

VI. Place a cover glass supported on thin pieces of glass over a drop of *Paramecium* culture in such a way that an air bubble is enclosed. Seal the cover glass with vaseline or melted wax from a thick taper. After some time the *Paramecia* will be found collected round the air bubble. This occurs only after relative exhaustion of oxygen in the water has been reached, and sometimes several hours may be necessary.

Reaction to oxygen

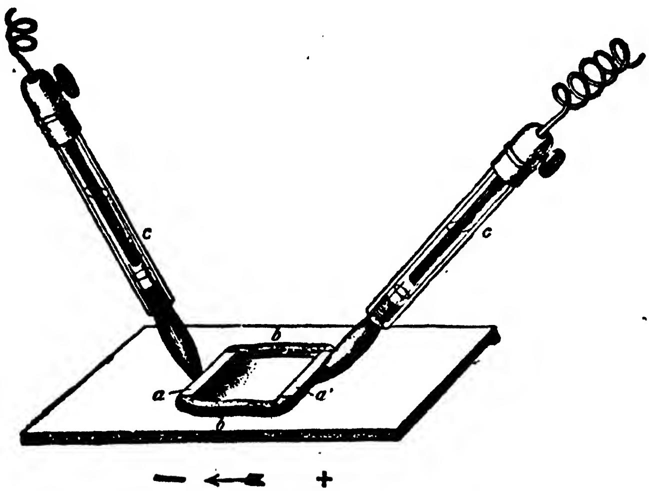


FIG. 9.—Method of demonstrating reaction of *Paramecium* to electric current. (From Gallenkamp's Catalogue).

(The following rather special reaction is for study by advanced students.)

A little cell is made on a glass slide by taking two strips of porcelain and two of glass and fixing them with canada balsam to the slide (see Fig. 9).

Reaction to electricity

A thick culture of *Paramecium* is placed in this shallow trough and observed under the microscope. The current from a six to eight-cell battery is brought to a couple of non-polarisable electrodes. (These can be purchased from Messrs. Gallenkamp & Co., London, or made by taking two pieces of glass tubing $1\frac{1}{2}$ inches × $\frac{1}{8}$ inch diam. and stopping up one end with a paste made of china clay and salt solution, which paste is produced into a kind of pencil. The tubes

are filled with concentrated zinc sulphate solution and stopped with corks through which a zinc rod passes.) One electrode is laid on each porcelain side of the cell. When the electric current passes, all the *Paramecia* swim towards one side—the negative electrode. If the direction of the current is changed, they change their direction also. Strong currents often produce diverse effects. The electric currents apparently act directly on the direction of cilia-beat, the animals are not merely transported by the current. There is no satisfactory explanation of this reaction, which is rather artificial, that is, 'a laboratory reaction,' not occurring in nature.

Trichocysts The trichocysts may be discharged by slight pressure on the cover glass over the animals. Another method is to introduce a little 1% acetic acid under the cover slip or a solution of methyl green acidified with acetic acid.

Reproduction Reproduction in *Paramecium* takes place by binary fission. A transverse division of the parent gives rise to two daughter individuals. During the process of division both the meganucleus and the micronucleus divide, and one of the two parent contractile vacuoles goes to each daughter individual. In well-fed creatures fission takes place two or three times a day.

At intervals in the life of a race of *Paramecia*, the succession of divisions is interrupted by a remarkable association of the animals in couples. The process is termed **Conjugation**, and the individuals participating in it are known as **Conjugants**. Apparently this temporary association of two individuals brings about a change in each which is accompanied by a kind of rejuvenescence. Recently new observations have been made in regard to the meaning of this, and students are referred for details to special papers.

Conjugation is essentially a changing over of portions of the micronuclei of the two individuals. The mechanism by which the exchange takes place is extremely interesting. The two conjugants become applied together by their ventral surfaces (Fig. 10, I.), and degeneration in the region of the gullets leads to a continuity of their protoplasm, but the most important events of the process centre round the behaviour of the micronuclei. As soon as the conjugants become

apposed to one another the micronucleus commences to enlarge (I. right), and it moves away from its normal position near the meganucleus. In each conjugant two successive divisions of the micronucleus give rise to four elements (II.), three of which disintegrate (III.) and the remaining one again divides into two (IV.). We now have two apparently similar micronuclei in each conjugant, but their difference is indicated by the next event, the actual exchange of material. The two micronuclei may be distinguished as the stationary

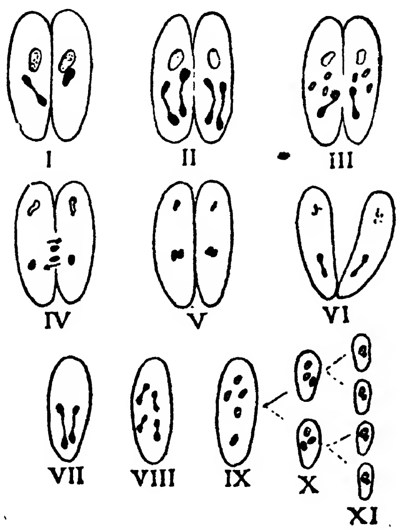


Fig. 10.—Conjugation in *Paramecium caudatum*.

nucleus and the migratory nucleus. The migratory nucleus of each conjugant passes over (IV.) and fuses with the stationary nucleus of the other (V.). Then the two *Paramecia* separate. They are now conveniently termed ex-conjugants.

Whilst the above changes have been taking place, the meganucleus has been gradually disintegrating, so that by the time the conjugants are about to separate, it has finally disappeared. Further changes result in the formation of four typical *Paramecia* from each of the uni-nucleated ex-conjugants. The nucleus divides three times, giving in succession two (VI.), four (VII.) and finally eight (VIII.) nuclei. Three of these are resorbed. One of the remaining five is different from the others and has the power of further division. It divides again, but this time the *Paramecium* divides. Two

divisions of this kind take place; the first division results in two individuals (X.), each provided with a micronucleus and two meganuclei, and the second division gives rise to four typical *Paramecia* (XI.).

In some species of *Paramecium* the final divisions are slightly different.

Conjugation and the succeeding division stages are not sexual reproduction. Conjugation may, however, be regarded as related to sexual processes. The essential feature is that two cells have approached, exchanged something, and reorganised their constitution. Having done this, the same two cells have separated. There is no reproduction. But the result of the change is that the individuals separating are in a rejuvenated state and able to continue reproduction by fission. The process is only found in the group of Protozoa to which *Paramecium* belongs.

Summary *Paramecium,* like *Amoeba,* is a tiny organism showing no division into cells, although there are two nuclei. Its structure, however, is much more complex than that of *Amoeba,* and so far as structure alone is concerned the group to which *Paramecium* belongs (Ciliata) is the most highly developed group of Protozoa. We have been able to demonstrate better than with *Amoeba* that this simple organism presents all the characteristic activities of the higher multicellular animals.

Ciliates occur practically universally. They are found in fresh water, in the sea, and upon, and within, other animals. Some of them can attach themselves periodically, whilst others become definitely attached organisms, *e.g. Vorticella.* Most of those living within other animals appear to do no harm, living merely as partners (*Opalina* in the frog's rectum, and other ciliates in the intestines of different animals). Relatively few are known to be harmful parasites, although it is stated that one species, *Balantidium coli,* in man (found in the intestine) is responsible for disease. Because *Paramecium* can be cultured with ease and hundreds, even thousands, of generations may be obtained in a reasonable time, it has been used to a very great extent in experiments on heredity and variation.

EUGLENA

Euglena is an example of another of the four great classes of the Protozoa, the class **Mastigophora** or **Flagellata.**

long protoplasmic processes called **Flagella.** *Euglena* has only one. In many ways these organisms are the simplest of all Protozoa, and some possess the green pigment called chlorophyll, which is so characteristic of plants.

Occurrence and preparation of cultures

Euglena viridis is a little Protozoan very common in puddles, slow-flowing ditches and stagnant roadside pools, to which it gives a green colour. Specimens may thus be easily obtained. A culture may be set going by taking a little of the water containing the organism and adding it to one of the following solutions :

(*a*)	Peptone	0·5	grm.
	Glucose	0·5	"
	Citric Acid	0·2	"
	Magnesium sulphate	0·02	"
	Potassium phosphate (KH_2PO_4)	0·05	"
	Water	100	c.cs.
(*b*)	Ammonium sulphate	0·2	grm.
	Potassium phosphate (KH_2PO_4)	0·2	"
	Magnesium sulphate	0·1	"
	Trace of iron sulphate ($FeSO_4$)		
	Tap water	200	c.cs.

General description

Place a little of the fluid containing *Euglena* on a slide under a microscope and cover with a thin cover glass. (The weight of it will slightly flatten the animals and hold them in the field of view.) *Euglena* is a very small spindle-shaped organism, large specimens of which may be about $\frac{1}{300}$ inch in length. The flagellum is situated at the blunter end, where it rises from the base of a funnel-shaped pit or gullet. This end moves foremost (it is regarded as the anterior end), the flagellum acting as a pulling organ, like the propeller of a ship when the vessel is going astern. The gullet opens into a spherical cavity (**Reservoir**) into which several **contractile vacuoles** discharge.

The very thin ectoplasm is bounded by a thin cuticular covering, which restrains the protoplasm so that it cannot stream out in pseudopodia, but it allows certain changes of shape (see Fig. 11), the so-called **Euglenoid movement.** Within the endoplasm there is a single **Nucleus** containing another distinct structure known as a **Nucleolus.**

The base of the flagellum passes into the reservoir, on the wall of which lies a red pigment spot (eye spot or **Stigma**). This is probably correlated with the marked sensitivity of the animal to light (see below), and it might be regarded as a very rudimentary type of visual organ.

The common species, *Euglena viridis*, is distinctly green in colour, due to the presence of numerous oval discs or **Chromatophores** suspended in the endoplasm. They contain chlorophyll, the green pigment so characteristic of most plants, and they enable *Euglena* to feed in the manner of a plant, by manufacture of food from the raw materials carbon di-oxide and water. A starch-like substance called **Paramylum** is formed in the light. This plant-like type of nutrition is called **Holophytic.** Probably *Euglena* is also able to absorb organic matter in solution by means of its outer surface—a type of nutrition termed **Saprophytic.** The more characteristic animal type of nutrition (the ingestion of solid particles of food) seen in *Amoeba* and *Paramecium* (**Holozoic** nutrition), does not seem to occur in *Euglena*, but it is found in other flagellates.

Reproduction takes place by longitudinal binary fission. The nucleus divides and then the body, one half taking the flagellum and the other half developing a new one. When conditions are unfavourable the organism encloses itself within a gelatinous cyst. Whilst encysted it may divide into two or more individuals.

Practical work

I. Place a little fluid containing numerous *Euglenae* in a small watch glass and set in front of a window, sheltering one half from the light with a piece of card. The *Euglenae* will settle either in the illuminated side or in the zone between the two, according to the intensity of the light. *Euglenae* are attracted by light (respond positively to light, that is, are *positively heliotropic*), if the light be not too powerful. Experiments have shown that the reaction of *Euglena* to light depends upon the light or shadow falling on the pigment spot.

II. Note, experiments may be made with other stimuli, as with *Paramecium*. *Euglena* does not appear to react to constant electric currents at all.

Euglena is a representative of a group of Protozoa which is very widespread in nature. Members of the class are found in fresh water (in collections of water of all sizes from roadside puddles to lakes), in the sea, in moist earth, and as parasites in or on other animals and even in plants. Some flagellates are so like the single-celled plants that it is difficult to say how they should be regarded. It is quite likely that the plant kingdom originated from such forms. On the whole the flagellates are simple in life history as well as structure. **Summary**

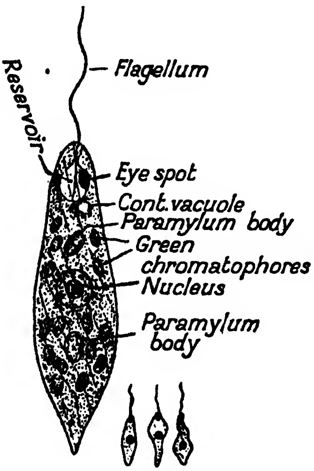


FIG. 11.—*Euglena viridis.* The small figures show changes in shape which accompany movements (so-called Euglenoid movement).

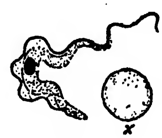


FIG. 12.—A Trypanosome (magnified about 1000); *x* is red-blood corpuscle drawn to about the same scale.

At certain times several species of flagellates occur floating in the sea and fresh water in enormous numbers. Under these conditions they become important as the food of larger organisms, which in turn are the food of fishes, and indirectly therefore of man. Some of these flagellates are well known as causing luminosity (so-called phosphorescence) in the sea.

Other flagellates are very deadly parasites. The human disease known as sleeping sickness in Africa is caused by a flagellate (*Trypanosoma*) in the cerebro-spinal fluid and blood. Certain horse and cattle diseases in Africa, India,

America, etc., are also caused by Trypanosomes. The flagellates which cause sleeping sickness are conveyed to man by Tsetse flies, and these same insects are responsible for carrying and introducing into horses and cattle some of the other trypanosome diseases. The possibility of many regions of Africa becoming trade centres and healthy areas even for natives is entirely a question of the successful control of these diseases. Other diseases of both the tropic and temperate regions are caused by members of this group of Protozoa.

MONOCYSTIS

The Sporozoa

This Protozoan is taken as an example of the fourth class of the phylum—the **Sporozoa**—a class which differs from the other three in being entirely parasitic. The members of the group lack means of locomotion almost entirely, except a few which are capable of amoeboid movement during certain stages. In structure they are therefore comparatively simple. On the other hand their life histories (*i.e.* the sum total of the changes which take place between the commencing stage of one generation and the corresponding stage of the next succeeding generation) are often very complex, and these microscopic parasitic organisms may pass part of their life in one animal host and part in another altogether different host.

Nutrition takes place neither by the intake of food particles nor by the plant-like method of constructing food out of raw materials (utilising the sun's energy), but always by the absorption of organic matter in solution.

Consequent on this there are no special organs for food capture or locomotion, and excretion is also simplified.

The Sporozoa are characterised by the predominant feature of all parasitic animals, the great development of reproductive activity.

Occurrence and preparation

Monocystis, the example taken, occurs as a somewhat spindle-shaped cell within the seminal vesicles of earthworms. To obtain specimens an earthworm (of good size and with prominent clitellum) should be killed with chloroform and carefully slit open down the upper or dorsal surface (the darker coloured surface). The seminal vesicles

should be conspicuous in the front third of the body. They should be recognised if Fig. 188 is used as a guide.

A portion of the contents of one of these seminal vesicles is spread *thinly* on a slide, preferably in a drop of 0·5% *Sodium chloride* solution, and covered with a cover glass. Examine under the microscope. (It is also advisable to tease up small bits of the wall of the seminal vesicles. Some of the stages of the parasite often adhere to the walls.)

General description

The contents of a seminal vesicle should look rather like Fig. 13. There are clumps of filament-like spermatozoa (the male reproductive cells of the earthworm) arranged

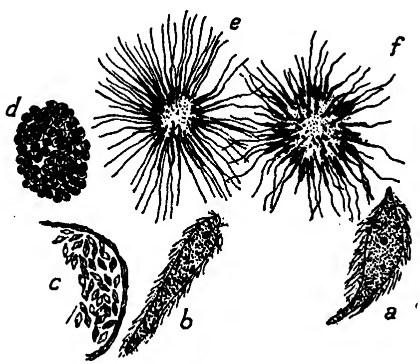


FIG. 13.—Contents of a seminal vesicle of an earthworm infected with *Monocystis*. Stages in the development of the spermatozoa are shown, and also stages in the life history of *Monocystis* (*a*, *b* and *c*).

like a fringe round a central mass of protoplasm (Fig. 13 *e* and *f*). It is in this central mass that *Monocystis* is found as a parasite.

Fig. 13 *a* and *b* are two fully grown parasites surrounded by the remains of spermatozoa and *c* is a stage in reproduction.

The adult organism is spindle-shaped—slightly flattened and with a spherical nucleus near the middle. The outer protoplasm may be called **Ectoplasm,** for it is somewhat marked off from the more internal protoplasm—the **Endoplasm,** which as usual is more opaque and granular owing to stores of reserve food material being present. Bounding the clear and rather firm ectoplasm is a thin **cuticle.**

Within the ectoplasmic region are delicate fibrils (the earliest forerunners of muscles in the animal kingdom and often met with in the Protozoa), called **Myoneme Fibrils.** They are not always easily seen unless specially stained microscope preparations are made. By means of these fibres slight movements may be made by the animal of the type seen in *Euglena.*

We have described what may be termed the **Trophozoite** stage, that is, the organism in its feeding and growing stage. (Fig. 14, A.)

Reproduction After a period of growth somewhat long compared with other Protozoa *Monocystis* prepares to reproduce. There is no simple division here. On the other hand we have an indication of what becomes sexual reproduction in the higher animals. A brief outline of the process will be given.

Whilst the sequence of stages in the reproduction of this organism has only been made out after long detailed study of all stages, it is not difficult to find the different stages and to recognise them in connection with the following description. The various stages should be sought for in the seminal vesicles of the earthworm. Some stages will be of more common occurrence than others.

Two *Monocystis* become applied together side by side and secrete a **Cyst** around themselves (see Fig. 14, B). Within this cyst the succeeding stages take place. First the nucleus of each *Monocystis* by repeated division gives rise to many nuclei. Each of these secondary nuclei with its surrounding protoplasm is known as a **Gamete.** The gametes fuse in pairs (Fig. 14 D. It is believed that the two members of a pair are representative of the two original *Monocystis* which were encysted—that is to say, one comes from one *Monocystis* and the other from its mate.) The fusion of each pair of gametes is complete, so that in every case a single uni-nucleate cell results. These are known as **Zygotes.** Round each zygote a hard shell is secreted, and it is then known as a **Spore.** The large cysts full of spores are often very numerous in the seminal vesicles (see Fig. 13 *c*).

Eventually the single nucleus of each spore also divides (into eight), and each spore then contains eight **Sporozoites.**

It is still unknown how infection of an earthworm takes place, but it is believed that the spores leave the body and

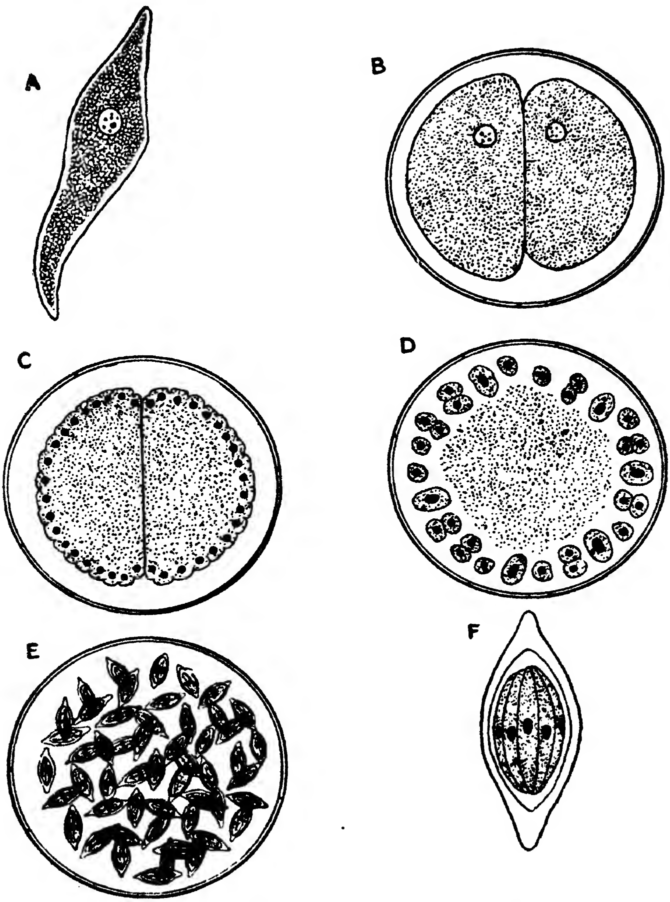


FIG. 14.—Diagram of the life history of *Monocystis*. *B*. Two encysted Monocystis preparatory to nuclear division. Each is called a gametocyte at this stage. *C*. Nuclei resulting from division, arranged at periphery. For further explanation see text. (From O'Donoghue.)

are distributed in some way, and that eventually they are swallowed by another worm. The action of the digestive juices is supposed to set free the sporozoites which would then have to reach the sperm sacs and commence the nutritive and growing stage. So far, this is only theory.

It is usually suggested that birds eating the worms set free the spores which reach the earth in the birds' faeces.

The Sporozoa are responsible for diseases in man and many other animals, and are of such importance that the study of the Protozoa has become of the greatest necessity in medicine. One of the best known of these sporozoan diseases is Malaria.

CONCLUSION TO PROTOZOA

Although only four types have been taken from this phylum, on which several volumes could be written, these four types illustrate the most characteristic features of the group. The Protozoa probably have the widest range of all animal groups for, although most are aquatic, they are found not only in the sea and fresh water, out in the middle of the great oceans as well as in the smallest puddles of a cart track, but they occur also in damp sand, soil and moss, and one entire class, the Sporozoa, is parasitic. Parasitic forms are also found in all the other classes. Numbers of species of Protozoa are quite common. In studying pond life, ciliates like the attached form *Carchesium* (Fig. 209) occur. *Kerona* and *Trichodina* may be found commonly on *Hydra*, and many flagellates other than *Euglena* will be met with, also numerous members of the group to which *Amoeba* belongs, such as the 'sun animalcule' (*Actinophrys*) and the beautiful *Actino-sphaerium* (Fig. 209). The shell-forming *Amoebae* (*Difflugia* and *Arcella*, Fig. 209), which belong to the same group, are also found in ponds.

Although the protoplasmic structure of the Protozoa appears simple, some of these organisms secrete the most beautiful shells. This is particularly true of the oceanic species belonging to the groups Foraminifera and Radiolaria, shells of which are illustrated in Fig. 15. These are so common floating in certain oceans that the constant descent of their tiny shells after death or reproductive stages results in the accumulation of a fine deposit on the ocean floor. This deposit is known as **Ooze.** Chalk is

formed in a similar way, and the somewhat broken shells can be recognised by carefully examining a piece of *natural* chalk with the microscope.

The types of Protozoa we have described illustrate certain of the modes of reproduction met with. The most characteristic and common method is that of fission. When the organism is full-grown it simply divides into two or more parts. This method of reproduction *is* found also

FIG. 15.—Foraminifera from chalk. (From Lulham.)

in the case of some multicellular animals (see Chapter XVI.), but it is naturally impossible for a highly organised animal to reproduce in this way.

Some form of sexual reproduction is also found in a great many Protozoa, but this is discussed in a later chapter.

The Protozoa we have selected show no division into cells, and indeed we might speak of each one as a single-celled animal. Some scientists, however, prefer to speak of them as *non-cellular*. It is difficult to frame a definition that will absolutely separate the Protozoa from the multicellular animals, because in a few cases a kind of colony is

formed when the cells which result from multiplication remain attached. In the case of *Volvox* (Fig. 210), a flagellate quite common in ponds, this leads to a very definite spherical colony which behaves like one animal. Whilst in most cases of colony formation each cell still remains unspecialised and performs all functions, a feature which we have seen is so characteristic of the Protozoa, in *Volvox* certain cells are set aside for reproduction. It cannot, however, be separated from its related forms, and its affinities to the Protozoa are obvious.

APPENDIX TO PROTOZOA

The Parasite causing Malaria

A protozoan which belongs to the class Sporozoa is now known to be responsible for one of the most widespread of all human diseases—Malaria.

It is stated that in our own Indian Empire no less than 100,000,000 people are affected annually, with 1,000,000 deaths annually, directly or indirectly due to it. There were nearly 6,000,000 cases in Russia in 1923. It is pre-eminently a disease of tropical and sub-tropical countries but is serious enough in Italy and Spain, and certain forms of the disease were once common in parts of England.

For many years it was believed that Malaria was due to the bad air of swampy regions. The association of Malaria with swamps is a correct observation, but the relationship has nothing to do with 'bad air', but to an insect—a genus of mosquitoes—whose early stages are aquatic. The mosquito not only carries the parasite but is a true host to it.

In the case of Monocystis it was seen that the parasite passed its life in the body of an earthworm where it was restricted to one organ—the seminal vesicle. The protozoan causing Malaria is parasitic in two different animals—man and mosquito. It passes certain stages in one and the rest of its life history in the other. This phenomenon is quite common amongst parasites and will be seen again when studying the tapeworm.

The actual parasites in the human blood were discovered by a Frenchman, Laveran, in 1880, but it was not until many years afterwards that the part played by the mosquito was discovered. The parasites are minute nucleated masses of protoplasm which enter the red blood corpuscles of man and grow within them, eventually destroying them. The various stages are shown in Fig. 16. The stage in the human blood corpuscle is known as the trophozoite stage. It corresponds to the individuals of Monocystis which grow up in the seminal vesicle of the earthworm. When full grown it reproduces asexually by dividing up into a number of small cells, the schizozoites (or merozoites). These infect other red blood corpuscles and the same cycle is repeated again and again. In this manner, after a number of days, the few cells which may have entered the human body (through the bite of a mosquito) will have given rise to thousands. This asexual cycle, which begins as a small schizozoite and ends when it is a full-grown trophozoite dividing into a

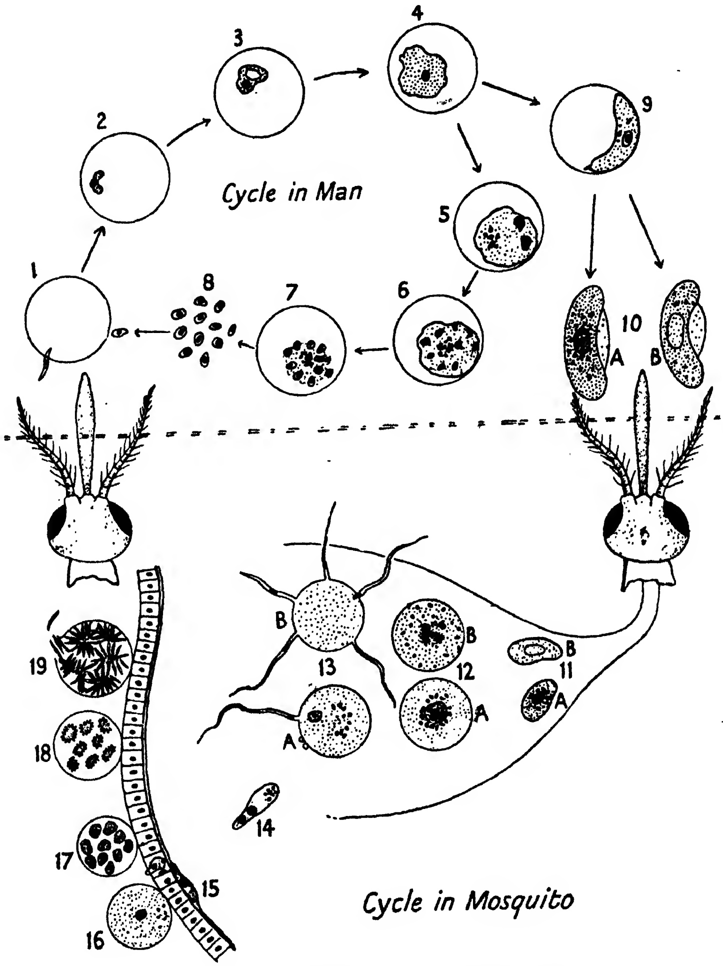


FIG. 16.—*Schematised life cycle of Malaria parasite.*

Stages 1–8 Schizogony (in man).
Stages 9–19 stages in Sporogony.

The stages above the dotted line represent those in man. On the right the female and male gametocytes (10 *A* and *B*) enter the stomach of the mosquito and the stages 11–14 follow within the stomach.

The Ookinete 14 bores through the stomach wall and stages 16–19 follow on the outside of the mosquito stomach. The sporozoites (19) enter man with the saliva of the mosquito. Stages 1–6 growth of sporozoite or schizozoite to full-grown trophozoite (6). 7 trophozoite dividing into schizozoites (8). 10 Gametocytes with remains of blood corpuscle attached. 12 Gametocytes forming gametes. 13 *A* fertilisation of female gamete. 13 *B* formation of male gametes. 16 to 19 stages called Oocysts, the single ookinete gives rise to very many sporozoites by repeated nuclear division. 19 Oocyst ruptures to release sporozoites.

new group of schizozoites, is called Schizogony. Eventually (and probably due to conditions resulting from the infection in the human body) the trophozoites follow a slightly different course and remain as larger uninucleate cells (rounded or sausage-shaped) which do not divide into schizozoites. These are called gametocytes and two kinds may be distinguished (micro- and macro-gametocytes—see Fig. 16). They cannot develop further in man. They *must* enter the body of a mosquito to continue their life history. But it is important to notice that only one kind of mosquito will do—the species of the genus Anopheles. If a mosquito of this kind bites and sucks the blood of an infected human being, the gametocytes continue their destined stages in the mosquito's stomach. All other stages as well as the red blood corpuscles are digested. Other sorts of mosquitoes biting a person infected with malaria probably digest all the stages. The parasite is thus specially adapted to life in the Anopheles mosquito and in man, and both are essential.

The stages in the mosquito are shown in the figure—it will be noted that sexual reproduction takes place within the mosquito and that eventually a large number of minute individuals—the sporozoites—are formed, which become lodged in the salivary glands of the infected mosquito—from whence they pass, with a little salivary juice, into any animal bitten. If the latter is a human being they may successfully enter red blood corpuscles and set going the asexual life cycle which eventually results in the complete infection of the body.

The account given above is reduced to the simplest possible terms. Actually there are three or four species of the parasite (*Plasmodium vivax*, *P. falciparum*, *P. malariae*, and *P. ovale*) and the effects they produce are slightly different. Thus the asexual cycle of *P. malariae* takes 72 hours, whilst that of *P. vivax* takes only 48, and *P. falciparum* is more irregular. The latter is the most abundant type in tropical countries.

From the above it will be seen that the mere presence of Anopheles mosquitoes in a region is not sufficient to cause malaria. The bite of the mosquito is harmless unless it is infected. Again, infected human beings from a malaria country can live without infecting other persons in a country where there are no mosquitoes. The complete life of the parasite requires the two hosts.

The menace of Malaria is usually attacked by attempts to destroy the Anopheles mosquito. As the insect lays its eggs on water (in which the early stages live—see page 404) a convenient method of destruction is available. Unfortunately it is not so easy in tropical countries to prevent the existence of odd collections of water, and even in British dominions which are not tropical the carelessness of the public permits of the breeding of many pests although science has shown them to be dangerous to human health. From the point of view of the well-being of humanity the discovery of the malaria parasite, and in particular its life history in the mosquito, has been one of the triumphs of biological science.

The student should compare the life history of the malaria parasite with that of Monocystis. It will be noted that the asexual cycle is missing in Monocystis. On the other hand, owing to the minute reproductive stages of the malaria parasite being handed over directly from one host to another, there are no such things as spores, the stage in Monocystis with a protective case suitable for resisting the unfavourable conditions in the soil, etc., until a new host is reached.

SECTION II

THE STUDY OF THE BIOLOGY OF THE MULTICELLULAR ANIMALS

INTRODUCTION

THE so-called multicellular animals or Metazoa comprise a vast assemblage of animals ranging from simple sponges and jellyfishes to man himself. In all these animals the cells of which the body is built are disposed very definitely, making up tissues of different kinds, and thus we have a 'body' which ranges in complexity from the simple fresh-water *Hydra*, in which only two layers of cells are recognisable, to the highly developed structure of the backboned or vertebrate animals. With the increase in structural complexity there is a corresponding specialisation of parts of the body, and thus the development of systems of organs all of which subserve special purposes. The outer surface of the animal becomes more or less protective and loses the power of absorbing food supplies. A special digestive cavity is therefore developed which most usually (not always) takes the form of a tube or alimentary canal running through the animal. But except in some of the lower multicellular animals, this necessitates a circulatory system to convey the digested food products to all parts and to carry away waste products.

Again, the outer surface of the body, being specialised for protection, may lose its power of absorbing oxygen, and thus special areas are developed for Respiration. These may project from the surface, when they are called gills, or they may be tucked into the body, forming bags or tubes. Special structures are also developed for Excretion and Reproduction. The increasing differentiation demands the harmonious working together of all parts of the body, and ~~thus a nervous system~~ appears with controlling centres and sense organs co-ordinating all parts and putting everything into touch with the environment. In the 'highest' groups a further controlling system appears consisting of the Endocrine Organs. Thus in an animal like the frog, for

example, there are definite limbs for moving from place to place, an alimentary canal into which food enters by the mouth, a liver and other digestive glands to produce digestive juices, lungs for respiration, kidneys to get rid of certain waste matter, heart and blood vessels to carry oxygen, food and waste matter from place to place in the body, sense organs for sight, hearing, smell, touch, etc., a central nervous system to co-ordinate and harmonise, reproductive organs to produce a new generation, endocrine glands like the Thyroid and Pituitary to control various chemical mechanisms of the body, and, since a large jelly-like mass of protoplasm needs a support, a skeletal system.

These are the characteristic systems of the multicellular animals, but they are not always developed as in the frog. The diversity of structure is indeed fascinating. A skeleton may be internal or on the outside, as in the crab, and its composition varies exceedingly. The respiratory organs may be gills to breathe in water like the fishes, or tubes ramifying throughout the body as in insects. We shall take a few animal types to illustrate this diversity of structure, whilst always remembering the universal occurrence of the typical functions to which we have so often referred.

III

THE COMPOSITION OF THE ANIMAL BODY AND OF THE SUBSTANCES USED AS FOOD

(This section may be passed over by junior students except for the paragraphs in larger type. It may also be considered advisable to leave this section to a later part of the course. It is placed here because, although it seems a little removed from either a study of the habits of animals or their structure, it is really a very necessary preliminary section to the next chapter, and it is too often neglected altogether.)

"Living" protoplasm

It will be easily realised that the chemical composition of protoplasm has been the subject of very much investigation. The explanation of all the unique phenomena of life is bound up with the nature of protoplasm—its physical and chemical properties. But chemical investigation, like other methods of study, cannot elucidate all the problems of its composition, because living protoplasm ceases to be living when we apply analytical reagents to it. 'Protoplasm usually presents the characters of a liquid, but when dead it appears to take on a rigid structure, like melted jelly when it "sets" or egg white when boiled.'

However, we can analyse and determine the products of the activity of living protoplasm, and we can discover the various chemical elements of which it is built and their proportions. We know something of the way these substances are combined within the body, and we are able to determine the nature and the qualities of the food necessary for growth, repair and supply of energy.

It is characteristic of animals (contrasted with plants) that they require their food in the form of more or less complex substances which are the products of animal or plant life. Green plants are able to build up their foods from simple raw materials. There are three main classes of animal foods, viz. **Fats, Carbohydrates** and **Proteins.** In

addition to these substances, water and certain salts are necessary and *small* quantities of substances (accessory food factors), which have been called **Vitamins.** Probably all these substances are not absolutely necessary. Proteins with water, salts and vitamins would suffice as materials for the building up of the animal body.

Vitamins

The investigation of the Vitamins has been one of the most interesting developments of biological chemistry during the last ten years. The term *Vitamin* is of comparatively recent date. The earliest thorough recognition that preserved food, which apparently contained all the substances necessary for energy and repair, was insufficient to sustain life healthily, and that very small quantities of other substances could produce remarkable effects, was the demonstration by Captain Cook that Scurvy could be prevented by the addition of a little lemon juice to the diet. Scurvy was a terrible disease in the days of sailing ships and long voyages. The benefits of lemon juice were, however, noted even in the sixteenth century.

Much more recently it was shown that Beri-beri, a nerve disease of oriental countries, was due to the diet being restricted to one food—polished rice. Unpolished rice with the ' bran ' on the grains might be sufficient to prevent it, and it was discovered that a substance could be extracted from the rice polishings with alcohol which would cure Beri-beri. This substance was called Vitamine B (later the ' e ' was dropped because the substances had no relationship with amines at all). It is now known as Vitamin B_1.

About this time (1906) Sir F. G. Hopkins, a great English pioneer in Vitamin research, suggested that *growth* was abnormal unless certain substances were present in the diet in small amounts. Ultimately this led to the discovery that some substances found dissolved in animal fats, like milk and particularly cod-liver oil, could prevent rickets in children. At first this substance was confused with that one found necessary for growth because both of them often occurred in the same foodstuffs, and both together came to be called Vitamin A.

By this discovery the old-fashioned use of cod-liver oil was placed on a scientific basis and some explanation reached for the potency of small doses. In fact it is characteristic of the Vitamins that only very small quantities are necessary compared with the weight of the real primary foodstuffs. It is largely due to this that Vitamin research has been difficult and is such a modern chapter in science.

At the stage reached above no one knew what a Vitamin was, nor was it possible to obtain any of these substances in concentrated form. By means of feeding experiments on rats and other animals, combined with medical observations, it was, however, possible to discover what animal or plant products contained the vitamins in greatest concentration.

To-day no less than seven or more accessory food substances or Vitamins have been recognised, and brilliant chemical research has led to the isolation and even synthesis of two of them—Ascorbic Acid (Vitamin C) and Calciferol (Vitamin D).

Vitamin A occurs plentifully in the liver oils of fish but is found in other food substances and in green vegetables. Its presence is necessary for proper growth. It is easily destroyed by heat. Vitamin B was found to be a mixture of several associated Vitamins and B_1 and B_2, and possibly several others, have been recognised. As we have seen, lack

of Vitamin B_1 causes Beri-beri. Possibly lack of Vitamin B_2 is responsible for another disease, Pellagra.

Vitamin C is the essential factor in lemon juice for preventing Scurvy. Its actual composition is now known. The compound has been named Ascorbic Acid. It is abundant in many fruits and vegetables ; unfortunately it is easily destroyed by heat and so is missing from many preserved and cooked foodstuffs. Lack of Vitamin D has been, and still is, responsible for rickets in children. Although often due to a real starvation diet, the disease may also occur owing to an *unsuitable* diet which lacks the Vitamin whilst possibly sufficient in quantity in other ways.

Sunlight may play a prominent part in the formation of this Vitamin in nature.

Another Vitamin is termed Vitamin E, but reference must be made (and continually) to the latest discoveries for the function and occurrence of this and other of these accessory food substances.

Several of the Vitamins are now being sold in concentrated form and are even added as commercial products to artificial foods which do not originally contain them.

The necessity for water will be obvious from the fact that **Water** a great proportion of the weight (more than half) of animals is due to water which enters into the composition of most parts of the body. The following tables indicate this:

PERCENTAGE COMPOSITION OF CERTAIN LIVING ORGANISMS

	Water.	Proteins.	Fats.	Carbohydrates.	Ash.
Lettuce leaves - -	94·33%	1·41	0·31	2·92	1·03
Jellyfish (*Rhizostoma*) -	95·39		1·608		3·00
Earthworm - - -	87·82		9·74		2·44
Crayfish - - -	77·11		16·82		9·06
Mouse - - - -	69·19		32·81		3·04

PERCENTAGE OF WATER IN PARTS OF THE HUMAN BODY

Skeleton - -	50%	Lungs - - -	79%
Muscle - - -	77%	Liver - - -	69%
Heart - - -	79%	Blood - - -	79%
Brain - - -	77%	Fatty tissue - -	15%

Water is absolutely necessary for the maintenance of life. (This is clearly indicated by the characters of deserts.) It is necessary within the cells as well as outside them as a solvent of other substances.

The most important elements in living substance are Carbon, Hydrogen, Nitrogen, Oxygen, Sodium, Potassium, Calcium, Sulphur, Magnesium, Chlorine, Iodine and Iron.

Mineral salts Several others are sometimes present. The mineral salts most important to animal life are the salts of Sodium, Potassium, Magnesium, Calcium and Iron, which contain phosphorus and chlorine—also the carbonates.

The salts serve many purposes in addition to supplying material for the actual composition of the body, as for example lime in bone. They enable substances otherwise insoluble in water to become soluble, they play a part in osmotic processes and so on.

Sodium and Potassium, Calcium and Magnesium never fail in the body fluids. Calcium and Magnesium play a curious antagonistic action to Sodium and Potassium. Thus an artificial sea water containing only common salt is actually poisonous to marine animals ; it is necessary to add the other salts. Iron is important in the case of animals with red blood. It is a constituent of the red substance known as haemoglobin.

Fats, carbohydrates and proteins From our point of view the fats, carbohydrates and proteins are the three most important groups of substances which are constituents of living matter. They are all Carbon compounds. This is characteristic of the great majority of the products of living protoplasm. But there are far more Carbon compounds known already than those which are directly concerned in vital processes. The chemistry of the Carbon compounds is usually spoken of as organic chemistry. It is peculiarly interesting for, owing to a special facility of carbon to combine with itself, it is possible to have compounds containing an extraordinarily large number of carbon atoms linked together. For a similar reason it is possible to have a tremendous number of slightly different varieties of a molecule.

It is said that as many as 1000 million stereoisomers of an albumin may exist, and it is noteworthy that even amongst the mammals the blood proteins of each species differ in constitution.

It is this which makes the life of a tiny cell so complex, and probably is at the bottom of the fact that there are so many different species of animals and plants in the world.

Carbohydrates are compounds of Carbon, Hydrogen and Oxygen. They are so called because the most important contain Hydrogen and Oxygen in the same relative proportions as in water. Many of them are important foodstuffs—for example, sugars and starches. They are the great energy-supplying materials, and are often stored as reserves in the body (see later). Under certain circumstances excess of carbohydrates may be converted into fats. It is doubtful whether they can be transformed into proteins.

There are three groups of Carbohydrates, known respectively as Monosaccharids, Disaccharids and Polysaccharids.

(I.) The sugars known as Monosaccharids are represented in nature by Glucose (grape sugar), Fructose, etc. Glucose often occurs in the animal body; it is found also in seeds, leaves and other parts of plants.

Fructose is a constituent of raw sugar and is more or less a plant product, occurring in fruits.

(II.) The Disaccharids may be regarded as originating by the fusion of two molecules of a monosaccharid with the loss of one molecule of water ($C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O$).

They are sweet, like the monosaccharids, but more stable and less likely to be broken up by micro-organisms. They are represented by Saccharose or Cane Sugar, common in the plant kingdom. Lactose is exclusively animal, and is produced by the milk-secreting glands. Maltose occurs in the animal body when starch is digested.

(III.) The most important Polysaccharids (constitution according to the formula $(C_6H_{10}O_5)_n$) are starch, glycogen and cellulose. They may be regarded as originating by the junction of a number of molecules of monosaccharids with loss of water molecules.

Starch is manufactured in green plants, where it is often found as a reserve stuff. It is insoluble in cold water. The soluble sugars are converted into this product, which can be split up again into sugars. As we shall see later, starch is converted into sugar in animal digestion.

Glycogen, a substance of frequent occurrence in the animal body, might almost be termed animal starch. It is formed and stored in the liver, but in recent years it has been recognised that

it is far more than a mere storage product. It is an absolutely essential substance for muscular contraction (see page 218) and there is a most interesting alternation between sugar (glucose) and glycogen which is formed in the muscles from glucose.

Cellulose is another Polysaccharid, but it is characteristic of plants, where it forms the walls of cells. It occurs only rarely in animals. It comes into importance, however, as an animal food in the case of curious creatures like the white ants and wood-boring molluscs, which are capable of subsisting on wood, and it must be taken into consideration in the digestive processes of herbivorous animals (see page 69).

Tests for carbohydrates

The reactions of grape sugar may be taken as typical of monosaccharids. Note that there are special tests for different sugars. The following tests are chosen for use in the digestive experiments of the next chapter.

Tests for grape sugar

(1) *Trommer's Test.* Make a solution of glucose alkaline by the addition of a little sodium hydrate solution. Then add copper sulphate solution drop by drop (shaking after each addition); the solution becomes deep blue. If an excess of copper sulphate solution is added, a precipitate of cupric hydrate will be formed. If the blue solution be heated nearly to boiling point a yellowish red precipitate of cuprous oxide will be formed.

(2) *Fehling's Test.* Add an equal quantity of Fehling's solution[1] to a little glucose solution and heat the mixture to boiling. A yellowish red precipitate is formed (cuprous oxide).

(3) *Silver Mirror Test.* Add a solution of glucose to an ammoniacal solution of silver nitrate[2] and warm gently. A mirror of metallic silver will form on the walls of the test tube, if it is very clean.

Fermentation of Glucose Solution. Add a little fresh yeast to glucose solution in a test tube, and place the latter in a warm place. Note bubbles and disappearance of the glucose.

Tests for cane sugar

Comparison of Cane Sugar with Glucose. Make the three tests (1, 2 and 3) described above on cane sugar solution.

[1] Fehling's Solution is prepared by making up two solutions as follows :—*Solution A.* Pure copper sulphate 14 grammes, water 200 c.c. *Solution B.* Rochelle Salt 69 grammes, Caustic Soda 26 grammes, Distilled Water 200 c.c. When required, equal parts of *A* and *B* are taken and mixed. Of this mixture use quantity desired.

[2] Silver Nitrate Solution for glucose silver mirror test is prepared by adding dilute ammonia to silver nitrate solution until the precipitate which forms is just redissolved.

Cane sugar reacts differently from grape sugar. Then, to a small quantity of cane sugar solution (about 10 c.c.), add a drop of dilute Hydrochloric Acid and boil for five minutes. Cool and neutralise with sodium carbonate so that the solution is blue to litmus. Repeat the Fehling test, which should now be positive. Heating with dilute acid has converted the cane sugar into so-called Invert Sugar, a mixture of grape sugar and fructose. Actually a disaccharid has been converted into a mixture of two monosaccharids. This is of special interest to us, because a similar change takes place in the manufacture of honey by the bee, where nectar (largely cane sugar) is inverted by change in the bee's stomach (see below) into about 73% invert sugar.

Boil a small quantity of starch in water (1 gramme to 500 c.c. H_2O, gently stirring) and allow to cool. Add a drop of a solution of Iodine in Potassium iodide. The result will be a deep blue violet colour. Drop a little of the iodine solution on bread and notice the same reaction. This is an extremely delicate test for starch. **Test for starch**

(Glycogen, often called animal starch, does not give this reaction. It is soluble in cold water, and the iodine solution in potassium iodide gives a characteristic red-brown coloured fluid with it. (Only one or two drops should be added.) The colour disappears on heating.)

FATS

Fats are compounds of fatty acids and glycerol.

In chemistry they are known as esters, and may be compared with salts in which an alcohol, glycerol (more familiarly known as glycerine), plays the part of a metal and replaces the hydrogen of the fatty acid.

Important fatty acids (biologically) are Stearic Acid, Palmitic Acid, Oleic Acid, and Butyric Acid. These give the fats tri-stearin (common in mutton fat), tripalmitin, triolein, and butyrin, but in animals the *natural* fats are mixtures of the above and other fats. The hardness of a fat depends upon the proportions of the different fats present—the fats of cold-blooded animals like the fishes are rather different from those of warm-blooded animals like sheep.

Fats and fatty acids are insoluble in water, but are soluble in alcohol, ether, etc. It is important to note that under certain circumstances they may be **Emulsified.** An

emulsion is a suspension of insoluble globules of one liquid in another. Thus an emulsion is formed when oil is shaken up thoroughly with water so that droplets of the oil are in a state of suspension in the water. Fats may be emulsified in the digestive tracts of animals under the influence of the digestive juices (see below). The chief use of fats as food is the production of energy. Weight for weight they produce twice as much energy as do proteins or carbohydrates. They are also the chief reserve stuffs in the animal body. In the whale, a thick deposit under the skin (**blubber**), serves as a necessary non-conducting layer to keep the body warm, the whale being 'warm-blooded.'

Experiments with emulsions

(1) Thoroughly shake up about 2 c.c. of neutral olive oil with 10 c.c. of distilled water. An emulsion is formed, but the substances separate again after a short time.

(2) Shake up 2 c.c. olive oil with 10 c.c. distilled water to which one drop of 8% sodium hydrate solution (as alkali) has been added. Note that a permanent emulsion is formed. A similar emulsion can be produced if a little solution of ox gall is mixed with the olive oil and water. In the intestine of vertebrate animals alkaline secretions from the pancreas are present, and gall (or bile) is also there. Fat is in a more suitable condition for digestion when it is in the form of an emulsion, because weight for weight the globules offer to the digestive juices a much larger surface for attack (see later).

Solubility of fats and soap formation

Test the solubility of fats in water, alcohol, benzene and ether.

Boil together about 5 grammes of lard and 25 c.c. of 10% alcoholic solution of sodium hydrate for about ten minutes. The lard will be converted into a soap, and if the reaction has been complete no oil drops will be seen.

Note.—Within the digestive tube of vertebrates and invertebrates fats are split up and fatty acids and glycerol are formed. If the digestive tract is alkaline, soaps will be formed. These substances, dissolved in the bile, are absorbed by the intestinal wall, and are then recombined within the cells to form fats. Bile is thus essential for the normal digestion of fat.

PROTEINS

These are most important and essential substances of animal food, and they play the most important part in the structure of the animal body. They make up the greater part of the 'solid' matter, and are found in fluids such as the blood and lymph. They agree in being composed essentially of the following elements: Carbon (50–55%), Hydrogen (6·6–7·3%), Oxygen (19–24%), Nitrogen (15–19%), Sulphur (0·3–2·4%), and Phosphorus (0·4–0·85%).

Though there are several groups of proteins they all react in a characteristic manner to certain tests. Their molecules are large (built up of very many atoms), and consequently they are **Colloidal** in nature (see below). Meat without fat is almost entirely protein and water, so is white of egg. Proteins are absolutely necessary to the building up 1
of protoplasm. They are essential for growth as well as 2
for repairing the waste continually going on in the body. 3
In addition to this they can be, and are, used as a source of both muscular energy and heat. In this respect, how- 4
ever, carbohydrates and fats are more suitable, and so it is necessary that the amounts of all these substances in the food should be correctly balanced for the needs of the animal (see Digestion, page 60).

Colloids

Proteins are found in the animal organism in the colloidal state. Since this is important from the point of view of the condition we speak of as 'life,' it is desirable to add a few more words, although the subject is not for an elementary work.

It was found by Thomas Graham (1861-1864) that dissolved substances behaved differently in regard to their capacity for passing through organic membranes like sausage skin or parchment paper. Some substances like salt and sugar (which crystallise easily) diffuse through such a membrane; others, like starch in solution, gelatine or glue and egg albumen do not pass through. The first class was distinguished as crystalloids and the second as colloids.

In colloid solutions or 'sols,' the dissolved particles are

from 2 to 100 $\mu\mu$ (1 $\mu\mu$ = one millionth of a millimetre) in diameter, much larger therefore than those in crystalloid solutions. When the refractivity of these particles for light differs sufficiently from that of the solvent, the path of a beam of light through the solution becomes visible, and by a special device it is possible with a microscope to see the light reflected from each particle.

Other consequences of their large size are: (1) they diffuse very slowly, (2) the larger particles are unable to diffuse through parchment paper, (3) the solutions are crystallisable only with difficulty or not at all, (4) when they are thrown out of solution they form either jellies or 'gels.'

Amongst the significant differences between a colloidal solution of gold in water and a colloidal solution of a protein such as gelatin in the same medium, it can be recognised that whilst there is a distinct affinity between the protein molecules and the water molecules, amongst which they are dispersed, there is no such intimate relationship between the gold particles and the water. The latter type of colloidal solution is said to be hydrophobic, the protein type is hydrophilic (water-loving). The terms lyophobic and lyophilic are also used for the more general aspect of this phenomenon, the former implies lack of affinity between the medium and the particles dispersed in it, the latter an attraction (fondness) for the medium. Thus the hydrophilic colloid can also be said to be lyophilic. It is the hydrophilic colloids like the proteins which are important in biology.

Everyone knows how a solution of gelatin will set to a more or less elastic jelly or gel when cold. This is a very characteristic state—important in the study of protoplasm. Whilst a gel may be said to be a solid, the substance formerly in colloidal solution (gelatin for example) has not separated visibly from the water. The change of state is due to change in the physical condition of the liquid. A network of protein particles exists in the gel with less freedom of movement of all molecules.

It is partly in consequence of their colloidal nature that the proteins form combinations with the carbohydrates, fats and salts, which render possible the various phenomena which go on in the living animal cells.

Classification of proteins

A chemical classification of animal proteins is out of the question, and in any case the composition is insufficiently known for such. The following may, however, be noted:

1. *Albumins.* Soluble in water and dilute solutions of salts, also in acid and alkaline solutions.

Examples.

Serum albumin (a protein of blood serum).
Egg albumen.

2. *Globulins.* Insoluble in water, but soluble in dilute solutions of salts and in weak acid and alkaline solutions.

Examples.

Serum globulin (found in blood serum).

Fibrinogen (found in blood and changes into fibrin when blood coagulates).

3. *Skeletal Proteins* (Skleroproteins). Albuminoids. Completely insoluble in water and other solutions except in very strong acids and alkalis.

Examples.

Keratin	horn, etc.
Collagen	in cartilage.
Chondrin	in cartilage.
Elastin	in sinews.
Spongin	in sponges.

4. *Compound Proteins.*

(*a*) Proteins and colour bodies (Chromoproteins).

Examples.

Haemoglobin and Haemocyanin (giving respectively the red colour of vertebrate blood and the bluish green colour of some invertebrate blood).

(*b*) Proteins and carbohydrates.

Examples.

Mucin in Mucus. Ovalbumen in Egg white.

(*c*) Proteins and phosphoric acid.

Example.

Casein in Cheese.

(*d*) Proteins and Nucleic Acids.

Examples.

Proteins of the nuclear protoplasm of animal cells.

5. There are also various related substances such as albumoses, peptones, etc.

Tests for proteins may be made on the following solution. Shake up a little egg white with about 20 times its volume of water to which a little common salt has been added (say 0·75%). Filter. **Tests for proteins**

Biuret Test. To a little of the protein solution add caustic soda solution and then copper sulphate solution (1%) drop by drop, stirring or shaking slightly after each drop. A violet colour appears.

Sulphur Reaction. Add a drop of lead acetate solution and sufficient caustic soda to re-dissolve the precipitate which forms. A brown colouration results. Boil, and a black precipitate with a smell of H_2S is formed. This indicates the presence of sulphur in the protein.

The Xanthoproteic Reaction. Add an equal quantity of diluted HNO_3 to a little protein solution. Warm. A yellow colour results, and this, by the *careful* addition of Ammonia *to the cooled solution*, changes to orange.

Test with Millon's Reagent. Add a little Millon's Reagent (made by dissolving 1 c.c. of Mercury in 20 c.c. of concentrated Nitric Acid and diluting the solution with two volumes of water). A white precipitate is formed, which becomes red on heating.

Note.—The students should observe that solutions of albumen are precipitated by alcohol, mercuric chloride (corrosive sublimate fixing solution—see page 465) and formalin (taking some time), and that they are coagulated by heating to boiling point.

IV

NUTRITION

ALL living organisms require food, and for several reasons. Life implies continuous change in the protoplasm of the cell. This change is accompanied by waste, and of necessity therefore a supply of material to make good the loss is required and comes from the food. Then again, if the organism is growing, it requires additional material to be converted into the protoplasm of the new parts. Besides this, a living animal is like a machine, in that it requires *energy* to enable it to perform its various activities. This energy is obtained, just as it is for many of our machines, by the combustion of fuel. The fuel in the first case is provided by the food.

The food must be regarded as the raw material, and for whatever purpose it is used it must first undergo various chemical changes. The sum total of all these changes, including those which accompany the building up of protoplasm as well as those which take place in the combustion and production of waste, are included under the head of **Metabolism.** We may speak of the metabolism of an animal or of a cell or part of an animal, and in each case we mean the whole cycle of chemical and physical phenomena which is inseparable from the life of that part.[1]

The rate of metabolism will obviously vary with the animal and also with the conditions prevailing at any time. Thus in a man lying asleep metabolic changes are taking place. Energy is being produced by the combustion of material of the body, and this is being used to sustain life.

[1] Strictly speaking the term metabolism should only include the chemical changes within the cells of an animal and thus the preparatory digestive changes in the alimentary canal are excluded.

In the example taken this is clear, because a certain temperature is kept up and the body is warm. If active muscle movements take place much more energy is naturally required, and the rate of combustion and therefore of the production of waste increases. Greater supplies of food will be required in such a case. Again, a growing animal needs additional supplies for the building up of new parts. Thus a man actively engaged in hard and continuous manual labour requires more food than a sedentary worker such as a clerk, and an active and growing child requires also a relatively large amount. The amount of food required for the supply of energy is, however, greatly in excess of that needed to replace tissue waste or for the building up of new tissues.

It follows that an organism cannot go on indefinitely without creating a necessity for supplies of material to provide for the wear and tear of tissues and to supply energy. In this respect the body may be likened to an electric accumulator driving a motor. To be efficient the accumulator must be supplied with electricity whilst the motor is working. If the supplies are stopped, the motor does not cease immediately, but goes on whilst the accumulator, depending on its own stores, gradually runs down till finally all motion ceases. Waste is a constant feature of living protoplasm, whether supplies to make up the wastage are forthcoming or not.

We have seen that the more or less crude material which is used by an organism is termed **Food**. This cannot be incorporated into protoplasm in its crude condition. In most cases it cannot even be distributed to different parts of the body in this raw state. Thus we recognise a definite sequence of events. Food has to be captured, then it has to be prepared for absorption and distribution within the body (digestion, and circulation in the blood stream); distribution is followed by cellular processes which result in the ordered and complete use of the new material, and then the downward processes may begin leading to the production of waste products.

Foods must be materials which can be converted

eventually into protoplasm, or manufactured by protoplasm or which can be burned (or oxidised) to provide energy. It would appear at first sight that their name was legion, but as we have seen in the previous section they fall into three main groups, the carbohydrates, fats and proteins. Animals must actually be provided with these substances. Plants, however, are characteristically different, and they can manufacture these rather complex foodstuffs from very simple raw materials. There is another important difference in the metabolism of animals and plants; whilst the chemical changes taking place in animals result in the consumption of material and the production of energy, the metabolic changes in plants result in a storage of material (and consequently a storage of potential energy).

Source and Capture of Animal Food

In the animal kingdom the apparatus for the capture of food is as diverse as its source, and the structures and habits involved are of fascinating interest by reason of this diversity. As the food must be in the form of carbohydrates, fats or proteins, it will be obvious that all animals are ultimately dependent upon the green plants for their food, for as stated above the latter alone are able to manufacture such complex organic substances from raw materials. This does not mean of course that all animals are vegetarians. There may be quite a long chain between the plants and the animals. Thus man feeds upon the cod—the codfish devours plaice (as well as crustacea)—plaice feed in their turn on molluscs, and these largely upon microscopic organisms, amongst which diatoms and the plant-like types may be numerous.

The herring feeds upon quite small floating crustacea of the sea, these feed upon micro-organisms floating in the waters, and ultimately we come again to the green plant cells.

Normally only a few animals are found feeding on a wide range of edible substances (omnivorous nutrition), most are restricted to a greater or less extent. There are carnivorous animals, such as the lion, wolf, etc., which are almost entirely flesh-eating. Others, like the cow and sheep, are purely herbivorous. The restriction may go

further, for some species of animals are restricted to one kind of diet, such as the blood-sucking bats or certain caterpillars which only eat one kind of leaf. Most parasites are restricted in this way to one kind of food. Many of the latter (like the tapeworm) live immersed in their food, which they absorb through their body-wall. The majority of animals which are free select the material at hand, taking what is both desirable and suitable. There are a few like

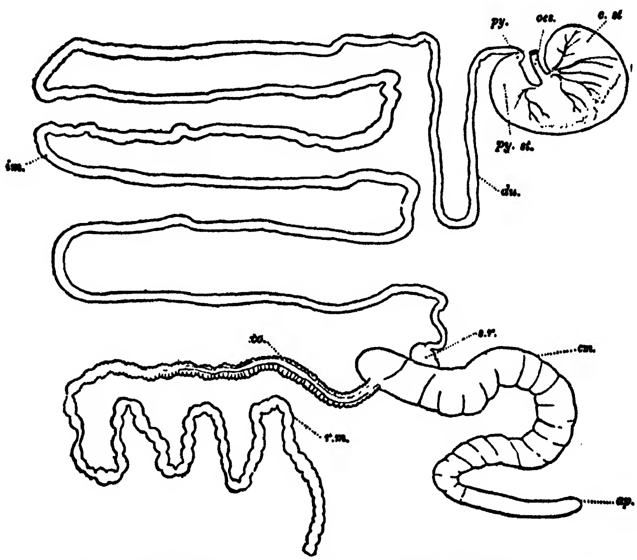


FIG. 17.—The alimentary canal of the rabbit removed from the body. (From Borradaile.)

ap., the appendix; *c. st*, and *py. st.*, parts of stomach; *cm.*, caecum; *co.*, *du.*, and *im.*, parts of intestine (colon, duodenum and ileum); *py.*, pylorus; *rm.*, rectum.

the earthworm which take quantities of soil or sand; they digest the organic material lying between the sand particles, which latter are passed out.

Mammalian nutrition

Examples.—Man, Dog or Cat and Sheep.

It is most convenient to describe the processes of nutrition by commencing with the highest animals. The organs involved in the lowest animals may be more simple, but the phenomena of digestion are best known in man and other mammalia. As a matter of fact the names of parts of the digestive system in the lower animals are often very

misleading (liver of the crab, for example). They were given when it was thought that the organs concerned were comparable to structures in man and performed the same functions. It is very essential therefore to know what the digestive organs in man really perform before turning to the 'lower' types. It is also easy to carry out certain experiments, using mammalian material which is obtainable at all times of the year.

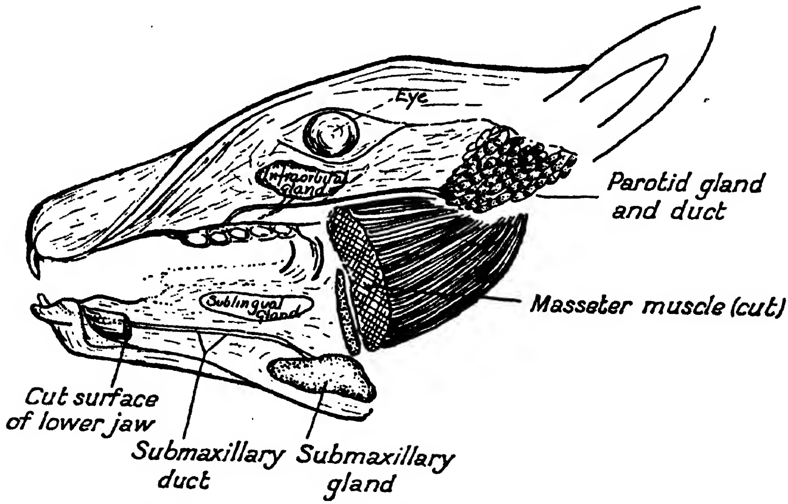


FIG. 18.—Diagrammatic sketch showing position of chief mouth glands in rabbit. (See text.)

In the mammalia food is prepared for absorption and nutrition in a tube—the alimentary canal—which runs from the mouth to the anus. This tube varies in character throughout, and the following specialised regions are to be distinguished (see illustrations, Figs. 17 and 20): **Mouth, Pharynx, Oesophagus, Stomach, Intestine, Rectum.**

Differences related to the type of feeding occur in the extent of development of these parts in different mammals. Thus the alimentary canal is shorter in carnivorous than in herbivorous animals, due to the greater length of the intestine in the latter. The intestine is the chief absorbing part of the alimentary canal, and consequently its area will have to be larger where the food is less digestible or less

concentrated. In the sheep, for example, the intestine is about 80 feet long.

Digestion begins in the Mouth

Digestion, that is the preparation of the food for absorption, begins in the mouth, where the teeth break it up and where it is moistened by the secretion from **Salivary Glands.** This is a mixed secretion from various glands (see Fig. 18)—different in different mammals—and the composition of the secretion from each varies. The glands are set in action by stimuli received not only by taste sense organs in the mouth, but also by touch organs and (certainly in the dog and man if not in the rabbit and other animals) by the sense of sight and by smell. The sight of food may do this.

The saliva has several functions. It moistens the food, rendering it suitable for swallowing and lubricating it for passage down the oesophagus. It dissolves dry food and helps to make taste possible. In addition it commences to digest the starch of the food. This is due to a digestive enzyme known as **Ptyalin.**[1] The changes which food undergoes during digestion are due to a number of different substances called **Enzymes.** Their action is complicated, and each one acts only upon certain substances.

An enzyme has been defined as a substance produced by living cells which acts by catalysis—that is, it causes chemical changes to take place, but it remains unchanged in quantity during the process.

Ptyalin is the enzyme produced by certain of the salivary glands, and its special function is to convert starch into sugar (maltose). Therefore the digestion of starches is commenced in the mouth and continues as the food passes down the oesophagus; other substances are unaffected by the salivary secretion.

Practical work on digestion

I. Collect a little human saliva in a test tube and add to it an equal amount of water. (The amount of saliva can be increased by rubbing the tongue against the lower gums.) Dilute some of this mixture with 20 times its volume of water and to 20 c.c. of it add 4 c.c. of 1% starch

[1] It is stated that the saliva of the dog does not contain ptyalin.

solution. Divide into two equal parts and immediately test one part for sugar with Fehling's solution (see page 48). It will be negative if the test is made at once. Shake the unused part, and take out a drop and mix it on a porcelain plate with a drop of iodine solution. The well-known blue colour of the starch test should result. Now take out drops in the same way at intervals of one to three minutes, and notice how the blue colour of the iodine test gradually fails to appear. Test the remainder with Fehling's solution. This should now indicate that sugar is present—that is, the starch has been converted into sugar.

II. Boil a little of the diluted saliva obtained as before, and then add starch solution. Perform the same tests as in the preceding experiment, and note that boiling has destroyed the power of the enzyme, for the starch remains unaffected and sugar is not produced.

III. Add a little saliva solution to pieces of hard-boiled egg, with acid or without, etc., etc. Note that no change takes place after some hours in a moderately warm place. Saliva will not digest proteins.

Stomach digestion

From the mouth the food passes down the oesophagus to the stomach. If it is fluid or soft it is almost 'shot' through the oesophagus by the action of swallowing. Solid food is forced down by **Peristaltic movement** of the muscles of the oesophagus. (For peristalsis, see *Daphnia*, page 80). Sometimes abnormally in man, the wave of contraction goes the other way and vomiting results. This is **Antiperistalsis**. It is normal in the sheep and cattle, which bring back food to the mouth to be chewed.

The **Stomach** in man (also rabbit, cat and dog, and most mammals) is a single chamber where the solid food may remain some hours. There is a ring-like muscle at the pyloric end (the exit to the intestine), and as the food is digested the thinner portions are let into the intestine from time to time. Whilst digestion is going on orderly movements take place in the stomach wall (the consequence of the activity of muscle fibres), and the food and digestive juices are thoroughly mixed.

The *secretions* of the stomach are derived from glands in the stomach wall, and as the glands differ in structure in different parts of the stomach, so does the composition of gastric juice also vary. It has been found to contain two enzymes—**Pepsin** and **Rennin**—(and possibly another), and a mineral acid—**Hydrochloric Acid.** (The gastric juice is the only body secretion containing a free acid.) The gastric juice is secreted normally so long as food remains in the stomach. The free acid in it stops to some extent the action of the saliva on starch, but as the interior of the swallowed food masses may remain alkaline for some time much salivary digestion often goes on in the stomach. Pepsin acts solely on the proteins of the food, but only in the presence of acid, so that the combined action of these secretions is necessary. The result is that flesh, cheese and other protein substances commence to be digested in the stomach.

So far as is known, the action of Rennin is confined to milk, the caseinogen of which it converts into insoluble casein, thus curdling the milk. The result is the production of small masses containing casein (the protein of milk); this reaction ensures that the milk protein remains in the stomach until digested by the pepsin instead of going straight through into the intestine (as liquids do).

Fats are not digested in the stomach, nor are starches, but the fats are liquefied by the heat of the body and partially prepared for the next section of the alimentary canal.

Digestion of proteins is not completed by pepsin in the stomach. The proteins are only broken down into proteoses and peptones which are then passed on for further treatment in the intestine.

Absorption by stomach

It is a common belief that the stomach is the chief organ for the absorption of digested food. This is not the case; indeed we have seen that digestion is not completed there, and that the digestion of fats has hardly begun. Possibly a little water, sugars, salts and some part of the digested protein may be absorbed, but the amount is probably not great.

Experiments on gastric digestion

I. Place a small piece of boiled white of egg or a piece of fibrin in a test tube with about 10 c.c. of water, to which a drop of chloroform water has been added to prevent

putrefaction due to bacteria. Leave for two or three hours in a warm place.

II. Set another similar tube side by side with the above, containing in addition a little dry pepsin (purchaseable), or some glycerine extract of pepsin,[1] and dilute Hydrochloric Acid to make the solution slightly acid to litmus paper. Note that the egg white becomes dissolved. Keep the solution for tests (see below).

III. Have another tube, a third, containing everything as in II. except the acid. Note that no change occurs. This serves to show that pepsin only acts in acid solutions.

IV. Take part of the filtrate from experiment II. and apply the Biuret test (see page 53). There should be a positive result, indicating that protein-like substances are in solution as the result of the action of pepsin. Boil the other part of the filtrate—there should be no precipitate—the liquid contains **Peptone,** a product of digestion which gives the protein Biuret reaction, but is not precipitated by heating.

V. Add a little pepsin solution with acid to starch solution (or add the extract from stomach), and allow to stand. Test for sugar after a time. The starch will remain unchanged by the gastric ferment.

VI. Add *gastric juice* to milk, and compare with addition of rennin.

Digestion and absorption in the intestine

It is in the intestines that the most profound digestive changes take place in the food, and in addition to this the absorption of the products of digestion occurs here almost entirely. Digestion in the human intestine is the result of the action of juices from three different sources, (*a*) the pancreas, (*b*) glands of the intestine wall and (*c*) liver (the secretion is known as bile). These juices are mixed, and their action takes place at the same time. (Before describing the process, it is necessary to warn the reader that the

Action of the pancreas

[1] The gastric juice can be obtained directly by purchasing some fresh pig stomach from an abattoir, washing it carefully and removing the inner lining. The latter is then cut up or pulverised in a mortar and left standing several hours in a mixture of glycerine and 0·5% HCl, about one litre.

liver in the vertebrate animals is not merely an organ for the secretion of bile, it has other very important functions; moreover the pancreas has quite another function besides the manufacture of pancreatic juice.)

The **Pancreatic Juice** is an alkaline secretion, and the sodium carbonate within it neutralises the acid in the semi-digested food coming from the stomach, so that the action of the gastric juice is stopped. The pancreatic juice eventually[1] contains three different digestive enzymes—**Trypsin** (which digests proteins), **Diastase** (which digests starches) and **Steapsin** (which splits up fats). Consequently the digestion of proteins which commenced in the stomach is completed; the digestion of starches which commenced in the mouth and stopped in the stomach is continued to completion, and the digestion of fats takes place.

The protein digestion goes so far that the products no longer give the Biuret reaction, and we get amongst other substances of which proteins are built up—amino acids. The amino acids are carried by the blood stream, and may be reconverted into proteins where needed. What is not required is broken down by the tissues and the liver, and urea is formed.

It should be noted that foods are not merely digested into *soluble* substances but into substances which may safely and usefully be absorbed into the body.

The action of the steapsin on the fats is strongly aided by the alkaline bile which is also poured into the intestine. The fats are split into glycerol and fatty acids. The acids join with the alkali to form soaps. The soaps and the bile together cause the particles of undigested fats to separate into small globules which makes further action on them more easy. The glycerol and soaps pass through the intestinal walls and are combined again within the cells to form fats which so enter the Lacteals.

[1] Eventually, because the potent enzyme Trypsin is not produced as such by the Pancreas. It would digest the two other enzymes were such the case. The Trypsin is secreted by the Pancreas in an inactive form called Trypsinogen and this is not converted into Trypsin until it meets another substance in the intestine, Enterokinase, a substance secreted by the intestinal walls.

Intestinal Glands. There are glands in the wall of the intestine which produce an intestinal juice. Their action is of a somewhat complicated nature and will not be touched upon here, but it is necessary to mention the remarkable mechanism which sets the pancreas secreting pancreatic juice.

The passage of acid semi-digested food from the stomach into the intestine causes the glands of the intestinal wall to produce a substance which has been called **Secretin.** This

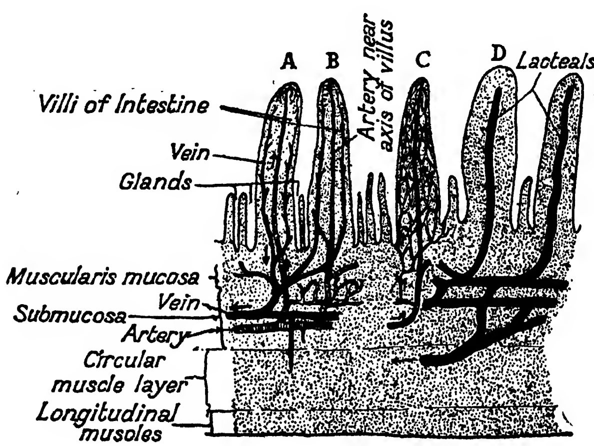


FIG. 19.—Diagram of blood and lymph vessels in wall of intestine. In each villus the vessels shown separately in *A*, *C* and *D* are to be found. Arteries and veins are both shown in villi *A* and *B*, the arterial capillaries in greater detail in *C*, and the lacteals only in *D* and *E*.

is poured not into the intestine, but into the blood, and it passes by way of the blood stream until, reaching the pancreas, its arrival stimulates this organ to secrete.

Absorption of digested food

Absorption of amino-acids, fluids, fats, sugars,[1] all products of digestion, takes place very readily through the wall of the intestine. There are, however, two paths for the absorption of digested foodstuffs. They may enter the blood at once through the minute blood vessels called **Capillaries** in the intestinal wall, or they may enter the

[1] It should be noted that it is in the form of monosaccharids that digested carbohydrates are absorbed. Sugars which are disaccharids —Maltose, Lactose, and cane sugar must be converted into monosaccharids. This is completed by the intestinal juice.

lymph circulation (see Blood, page 129) by the lymph capillaries known as **Lacteals.** The greater mass of the fats take the latter path, the other products enter the blood vessels of the portal system and go to the liver.

Experiments on intestinal digestion

I. Take a 1% solution of pancreatic extract or, preferably, make an extract of sheep's pancreas by purchasing a fresh pancreas (sometimes called stomach sweetbread). Chop it up or crush and soak in diluted glycerine for some hours, and finally filter. Take a few c.c. of the pancreas extract and add a little Sodium Carbonate solution so that the mixture is weakly alkaline (10 c.c. 1% pancreatic extract,[1] 2 c.c. 0·4% sodium carbonate solution), also a drop or two of toluol or chloroform to prevent bacterial action. Place a small piece of washed fibrin (or a piece of boiled white of egg) in the tube containing this solution and set in a warm place. The fibrin will be digested, it is gradually dissolved. Keep the solution for tests.

Repeat the experiment in other tubes:

(*a*) leaving out the sodium carbonate;

(*b*) adding weak HCl so that the mixture is acid to litmus;

(*c*) without pancreatic extract, but otherwise as in the above experiment.

Note that the digestion of fibrin goes best in the alkaline pancreatic juice and that pancreatic juice fails to act in an acid medium.

II. Repeat the saliva experiments on starch, using pancreatic juice. Note that pancreatic juice converts starch into sugar.

The liver

It is very necessary to describe here some of the functions of the liver of vertebrate animals, because so many other organs in the 'lower' animals have been called livers, with little reason and usually incorrectly. The liver is first a great regulating organ placed so as to intercept the blood containing the newly absorbed foodstuffs coming from the intestine before this passes on to the whole system. In the second place it is a gland which produces the substance

[1] Benger's Pancreatic Extract has been found most suitable for illustrating pancreatic digestion, when it is not desired to extract a pancreas or it is difficult to obtain a fresh one.

known as **Bile.** Two other functions are the formation of **Urea** and the formation and storage of **Glycogen.** There are also other functions concerned with metabolism. The liver is thus both a laboratory and a storehouse.

The action of the secretion of bile which is poured into the intestine is at first sight wholly digestive. The function of bile is, however, not so simple as this. Bile is partly an excretion of waste products of metabolism and partly a juice playing an important rôle in the absorption of fats. It helps to emulsify the fats and aids the pancreatic juice in splitting them into fatty acids and glycerine. As we have seen above, it also is concerned in the absorption of the digested products.

Glycogen in liver

The formation of glycogen from carbohydrate substances found in the blood is a very important function of the liver. Glycogen is an animal starch. The amount formed and stored in the liver depends upon the quantity of carbohydrates in the food and upon other conditions of the body. The glycogen is reconverted into sugar and passed to the tissues of the body (especially the muscles) as required. The liver thus regulates the supply and amount of carbohydrates in the blood.

Formation of urea

The formation of the waste substance urea in the liver is surprising at first sight, because this substance is associated so closely with the kidneys—the excretory organs of the vertebrate (see page 329). It is known now that the kidneys, which eliminate the urea from the body, do not manufacture it. At least part of it is formed in the liver and is then given to the blood and excreted by the kidney. Urea is formed from the amino acids, products of protein digestion (it is also formed from the amino-acids which result from tissue wear and tear). Amino acids which are not required for building up tissue proteins are broken up. The nitrogenous part is separated off as Ammonia and converted into Urea. The residue is passed on to the tissues to be utilised in the form of carbohydrates.

The functions of the liver of vertebrates are therefore several, and the name 'liver' should not be applied to organs of invertebrate animals unless they are really related

structures or at least perform exactly the same functions. One might say that this is nowhere the case.

Other enzymes reach the intestine in the intestinal juice—secretions from the walls of the intestine which complete the digestion commenced by the pancreatic juice.

We have touched upon the functions of the different parts of the alimentary canal, but said nothing about the wonderful harmony of control which is exhibited by this as by every system in the living organism.

The presence of a mass of food at the back of the mouth (or indeed any mass there) stimulates the muscles of the pharynx wall, at the same time closing the entrances to the lungs and nose. The food is conveyed to the stomach. Here it is kept and churned about, the opening from the stomach to the intestine being guarded by a circular muscle (the pyloric sphincter muscle). But the stimuli which set the stomach working, and its glands secreting, come from the sense organs of sight, smell and taste. They may have preceded the arrival of the food. The proper action of the stomach is dependent on many factors, and the emotional condition of the animal may easily put the whole mechanism out of gear. What determines the opening of the door which from time to time allows the semi-digested food to pass on into the intestine? Apparently the chemical condition of the materials in its neighbourhood, and the condition of the contents of the intestine. [The stimulus of the pancreas to action by the chemical agent, secretin, has been mentioned in the previous pages.]

V

NUTRITION

FOOD CAPTURE AND DIGESTION. (*Continued.*)

(*Examples.*—Sheep, Frog, Herring and Dogfish, Lobster or Crayfish, Daphnia, Bee, Housefly, Cockroach, Tape-worm, Hydra.)

The sheep

THE most important features to be noticed in connection with the nutrition of the sheep are common to the cow and the related animals known as the Ruminants. They are associated with the habit of breaking off large quantities of herbage, which are swallowed rapidly and without mastication. This food passes down the oesophagus and enters two large chambers (which with two following chambers are spoken of as the stomach) where it is stored. Strictly speaking, only the last chamber of the four is comparable with the stomach of man or the dog, since only these have gastric glands. The first two storage chambers are known as the **Paunch** and **Reticulum** (or honeycomb) respectively. (Examine a sheep's stomach and refer to figure for explanation.)

Whilst the vegetable food accumulates in the paunch, a certain amount of digestion may take placé owing to the action of saliva, but the most important change is a breaking down of the cellulose walls of the plant cells and a consequent setting free of the contents. (This appears to be due to the action of the bacteria which are present.) After a time the sheep ceases to crop the herbage, lies down and returns the food up the oesophagus in the form of large pellets to the mouth, where it is now thoroughly masticated (chewing the cud). It then passes down the oesophagus a second time, but on this occasion is directed along a groove into the third chamber (the **Manyplies**), where it is reduced to a fine state of division by the numerous folds of

the wall. Finally it reaches the true stomach, where protein digestion commences.

The frog In the frog digestion does not commence until the stomach is reached, for there are no true salivary glands secreting ptyalin, although mucus glands are present in the mouth. Food is usually swallowed whole. The tongue is a muscular flap attached to the floor of the mouth, but its free end is directed backward when in the mouth. Food is captured by throwing the free end over and out

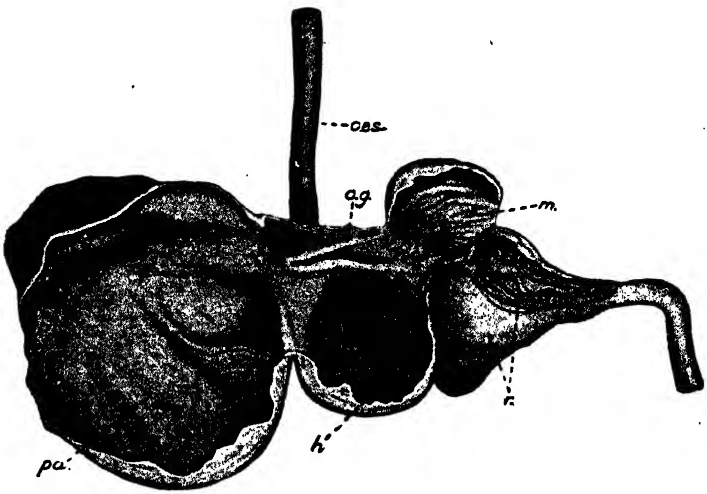


FIG. 20.—Stomach of sheep partly dissected to show internal structure. (From Dakin's *Animal Biology*.)
h, Reticulum; *m.*, Manyplies; *oes.*, oesophagus; *o.g.*, oesophageal groove; *pa.*, paunch; *r.*, true stomach.

of the mouth—in fact, shooting it at the prey. The fly, or whatever else the frog successfully shoots in this manner, adheres to the sticky end, which is then retracted. There is nothing to add to what has been given above in regard to digestion in the stomach and intestines.

The tadpole stage of the frog is herbivorous, whilst the adult frog feeds on animal food. It is interesting therefore to find that at the time of metamorphosis the intestine actually becomes shorter in length. Frog tadpoles can, however, be made to take flesh. If some tadpoles from a batch of eggs are fed on this diet and the rest on vegetable

matter, a difference in the length of the alimentary canal will be seen. (Fig. 23.) Thus here again we find that length of the intestine bears a relation to the type of food.

There is so great a diversity in the feeding habits of fish that it is only possible to give an outline sketch of some types. Most fish are either carnivorous or herbivorous, far fewer are omnivorous. The following types may be mentioned: **Feeding habits of fish**

(*a*) Fish which feed on smaller fish or other actively moving aquatic animals (some Sharks, Mackerel, Whiting and Turbot);

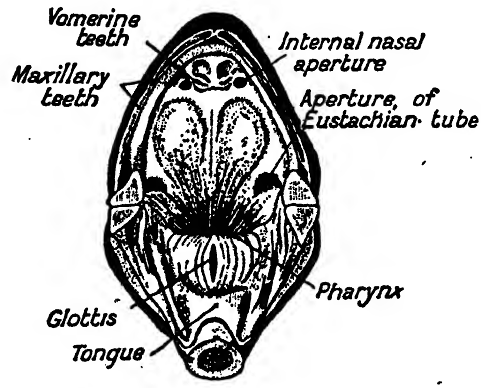


FIG. 21.—Mouth of frog. (After Röseler and Lamprecht.)

(*b*) Feeders upon Molluscs or Crustacea with hard shells (Cod, Plaice and others);

(*c*) Feeders upon soft-bodied animals like worms and sea slugs (Sole);

(*d*) Feeders on the Plankton (Herring—see page 393 for Plankton);

(*e*) Plant eaters (Mullets).

Many fish, however, might be classed under two or even more of the headings given above. Frequently there are differences in the structure of the mouth which are related to these feeding habits. Thus fish which feed on actively moving creatures have sharp teeth, with the points directed backwards in order to prevent their prey slipping away. Shellfish-eaters often have flat teeth adapted for grinding

and breaking up shells (some of the Rays, for example). The herring is a good example of the plankton feeders. In this type an effective filtering mechanism is present. Each gill arch bears a double series of bony rods, which project like the teeth of a comb. They are termed **Gill-rakers,** and their function is to strain the water which enters by the mouth on its way to the gills. Any particles thus strained out are retained and passed on to the oesophagus.

Examine jaws and tongue of frog, teeth and mouth of dogfish or ray, and also head of herring (see Figs. 21 and 25).

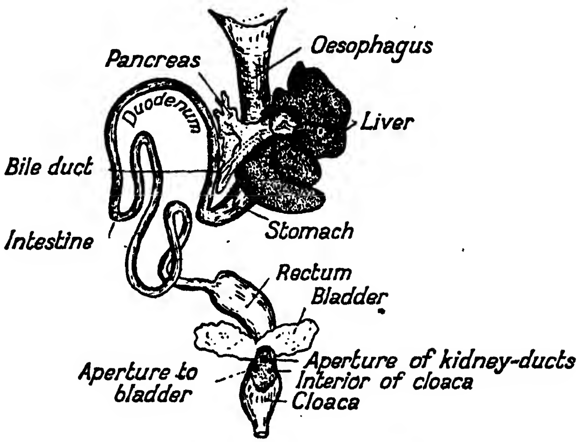


Fig. 22.—Alimentary canal of frog.

Digestion in fishes

As a rule there are no digestive glands in the mouth or in the oesophagus of fishes. In Elasmobranchs (the dogfish is an example) the oesophagus opens into a well-marked and relatively large stomach in which two regions may be distinguished, a large cardiac sac and a narrow pyloric portion. As far as is certainly known the glands of the stomach wall secrete a protein-digesting fluid containing acid and an enzyme like pepsin. It is not clear whether this gastric juice has not other digestive properties as well. The liver produces bile, and there is a definite pancreas from which a duct leads to the intestine, where further digestion (possibly like the type already described in higher animals) takes place.

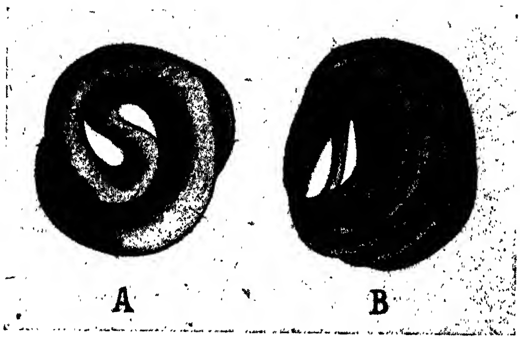
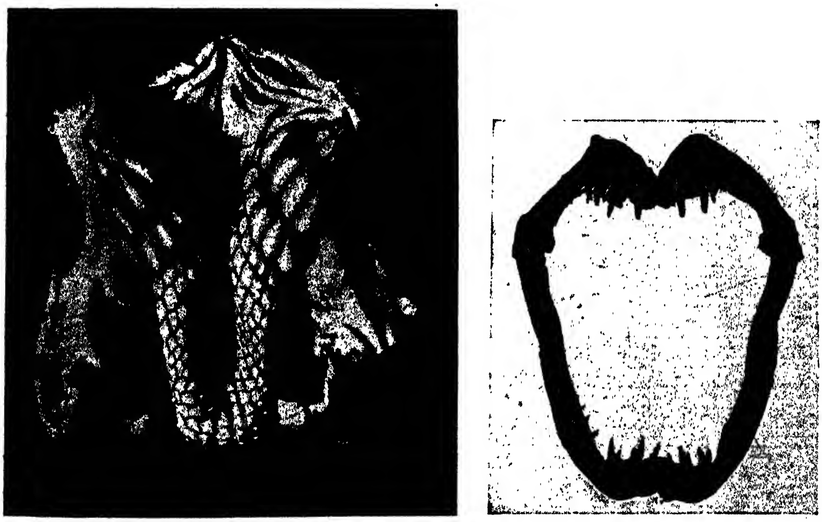


Fig. 23.—Intestine from tadpoles.
A fed on meat. *B*, fed on vegetarian diet.



A *B*

Fig. 24.—Differences in fish dentition.

A. Port Jackson shark with crushing teeth for breaking shells etc.

B. Blue nurse shark with sharp teeth for catching prey.

(From Dakin.)

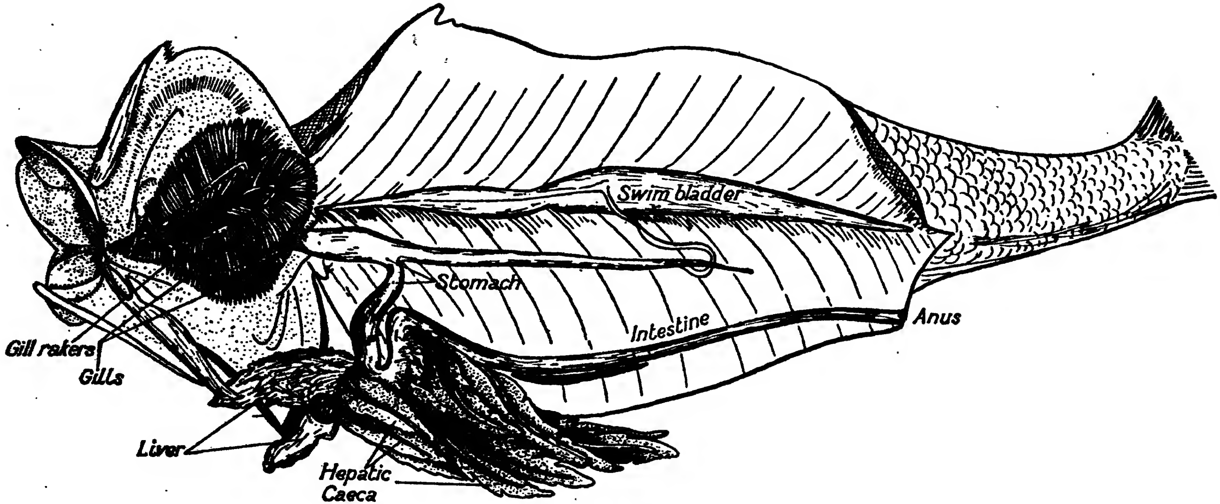


FIG. 25.—Herring dissected to show gill-rakers and alimentary canal.

A characteristic feature of the intestine of sharks, dog-fish, rays, etc., is the **Spiral Valve.** This is a fold of the wall which only allows food matters to pass down the

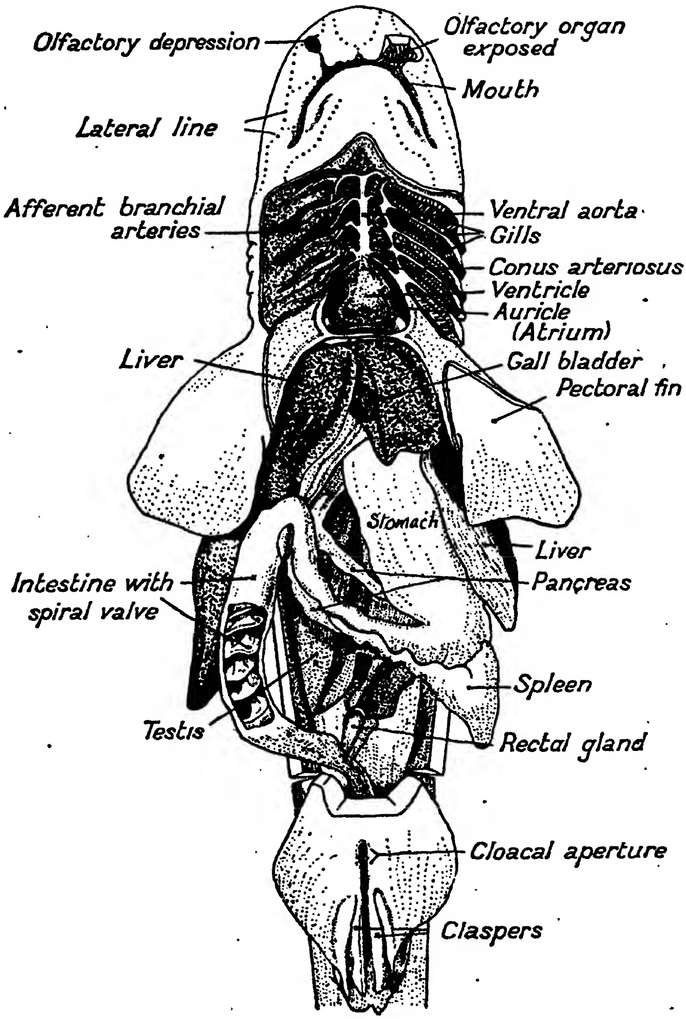


FIG. 26.—Dissection of male dogfish to show heart, afferent gill vessels and organs of body cavity. (After Röseler and Lamprecht.)

intestine in a spiral. It increases the area of absorption and brings the digested food in closer contact with it. This feature is absent in bony fishes like the herring, etc., and even in bony fishes which are vegetable feeders.

Bony Fishes.—In these fishes, in addition to the absence of the spiral valve in the intestine, there is a complete difference in the form of the pancreas, so that at first sight it seems to be missing altogether; the gland is actually present, but it is in a scattered condition, and is therefore seen only in microscopic preparations.

Another feature of the intestine is the presence of small blind diverticula. There are about 120 of these in the whiting, about 200 in the mackerel and 20 in the herring (see Fig. 25). Whether they are organs producing a digestive juice or places of absorption, or both, remains obscure.

Experiments with extracts show that protein digestion begins in the stomach of the plaice and no digestion of fat or carbohydrate occurs there. In the intestine digestion of protein continues with digestion of fats and carbohydrates. The stomach is acid and the intestine alkaline as in higher animals.

As might be expected, the functions of the alimentary canal and its attached organs in an invertebrate animal are often very different from those we have described as characteristic of the vertebrate. Thus an organ called a salivary gland in the bee or the snail *may* secrete a starch-digesting enzyme, but not necessarily so, and the organs often given the name of *liver* are not of the same structure or function as the true liver typical of vertebrates.

Feeding and digestion in crayfish

The Crayfish—like the lobster and crab—is a carnivorous animal. Food is captured by the aid of the great claws and is broken up by the **Mandibles** (see Fig. 245). It is then passed to the opening of the mouth by appendages known as the third pair of **Maxillipedes** (which are more like the ordinary walking limbs and not provided with chewing parts). Whilst the mandibles are at work, the **Maxillae** and neighbouring appendages prevent the finer particles of food from drifting away.

Practical Work. Examine the appendages carefully and dissect out the alimentary canal of the crayfish. (See Fig. 27 and pages 77 and 78 for notes.)

The food passes into the oesophagus. Probably glands open here, but they are not very obvious, and their function

is unknown. The oesophagus is a short tube leading to the so-called 'stomach.' This again is not to be compared with the stomach of the vertebrates. It is divided into two chambers. The front one may be called the **Mill Chamber** (or cardiac fore gut), and the second one the **Filter Chamber** (or pyloric fore gut). Behind the filter chamber a long straight tube leads back to the anus. Now the oesophagus and the so-called stomach are both lined with chitin—a layer continuous with the hard shell which

Alimentary canal of crayfish

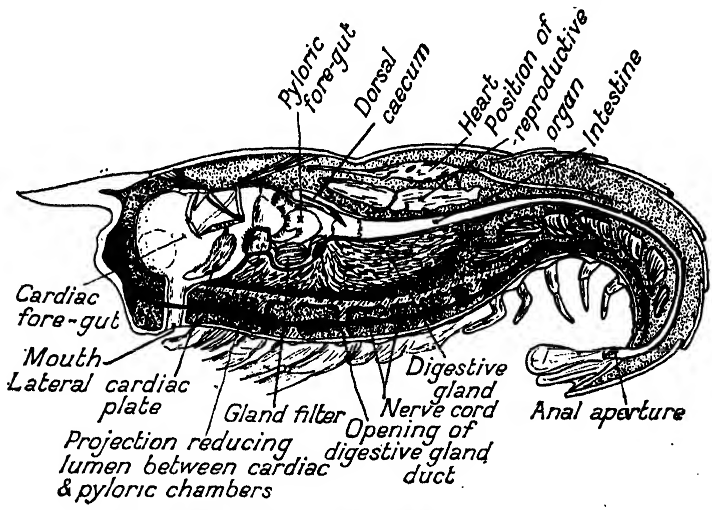


FIG. 27.—Diagram of section through Crayfish to show alimentary canal.

encases the animal. The same feature is met again in the greater part of the intestine. The only part of the alimentary canal free from this impervious horny layer is the short stretch just behind the filter chamber, where the so-called liver (Fig. 27, Digestive Gland) opens. This then is the part where we must look for absorption of food, and it is the only part which corresponds to the stomach and intestine of the frog.

The structure of the mill chamber (Fig. 27) is rather complicated. It is best to remove this organ from a large lobster and, after washing it out, to observe the interior through a small hole which may be cut at the anterior end. The lining of the mill chamber is hardened in places to

form little ossicles, some of which bear teeth. These project into the interior and can be brought together by muscular action in order to break up the food. The filter chamber bears structures which prevent the passage of hard parts of the food, but allow fine particles to pass on. Apparently hard unbroken parts may be sent forward again to the mouth, and even thrown out there.

Digestion and absorption of food—crayfish

Some digestion takes place in the mill chamber, but the digestive juice does not originate there. It comes from the so-called liver and enters the alimentary canal *behind* the filter chamber, then passing forward. This juice digests proteins, fats and carbohydrates. Its action is therefore more like pancreatic juice than anything else.

Digested matter in practically a fluid state passes into the mid-gut region behind the filter chamber. There it is actually caused to enter the 'liver,' which we had better term the **Digestive Gland,** where absorption takes place. The large digestive gland of the crayfish, lobster or crab is therefore an organ for the absorption of food as well as for the production of a digestive juice. But this does not exhaust its functions, for it probably stores reserve materials and also excretes. The long so-called intestine only conveys waste to the exterior.

Note.—At certain times before a moult, two lining plates known as crab's eyes or gastroliths may be found in the chewing stomach. Their function is a little uncertain, possibly a store of lime for hardening the new shell.

Experiments in crustacean digestion

The digestive juice of a living crayfish or lobster can be obtained by introducing a small pipette up the oesophagus into the mill chamber. (It may be necessary to use several animals until sufficient fluid is obtained.) Test the action of this juice by adding a little, diluted with water, to:

(*a*) Starch solution.—The starch colouration with iodine should gradually disappear as the starch is digested.

(*b*) Fibrin (or hard egg-white).[1]—Proteins are digested. Test the filtrate with the Biuret test. This digestion may be found to go well only in a slightly alkaline solution

[1] Fibrin appears to be most suitable for these tests.

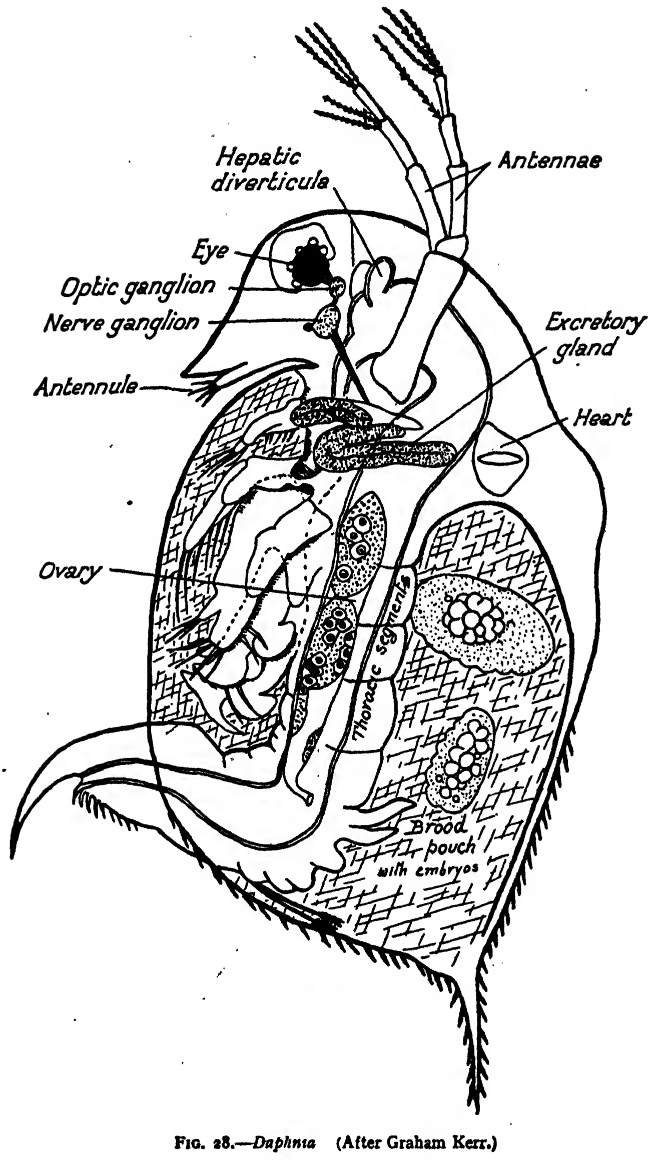


FIG. 28.—*Daphnia* (After Graham Kerr.)

(a drop or two of 2% sodium carbonate solution will be sufficient for this).

There is more than one enzyme present and it is impossible to compare the juice exactly with that of the stomach or pancreas of higher animals.

Daphnia

Daphnia (Fig. 28) is a small crustacean found almost everywhere in fresh-water ponds and ditches. It is a familiar object in ponds, and is commonly known as the 'water flea.' Daphnia is so transparent that one can see all the very simple digestive organs without dissection, and thus it is possible to observe such features as peristaltic movement in living specimens with the greatest of ease.

Food and Food Capture.—There are seven pairs of small appendages borne on the ventral surface of Daphnia (see Fig. 28), and of these the first pair are Mandibles, the next are a pair of Maxillae and the others are little flattened appendages with tiny spines or bristles. The constant movement of these appendages sets up and strains a current of water. Small particles of all sorts—tiny plants and animal cells, particles of debris, anything that is in the water and is small enough—are collected by the mandibles and sucked into the oesophagus by the movements of the alimentary canal.

The food consists chiefly of the smallest plant cells, bacteria and organic debris, whatever is most abundant at the time.

The alimentary canal is very simple in structure (see Fig. 28), and, with the exception of two little blind pouches projecting forwards, it is almost a straight tube without any special glands opening into it. The first part is termed the oesophagus, the next section which gives off the diverticula in front is the mid-gut, and the end portion may be called the hind-gut. Food is digested in the mid-gut. If the food is stained with neutral red, the cells of the little diverticula take up a slightly different colour from the rest—but little is known of the ferments produced.

Peristalsis seen in living Daphnia

The term **peristalsis** is given to a form of movement in a tube like the intestine when a constriction of the walls begins at a certain point and passes onwards like a wave.

Behind the advancing constriction the walls gradually relax. The movement is due to the contractions of the muscle fibres of the layer of muscle surrounding the alimentary canal and forming part of its wall.

These peristaltic waves in *Daphnia* pass from the mouth, carrying masses of food along the oesophagus to the mid-

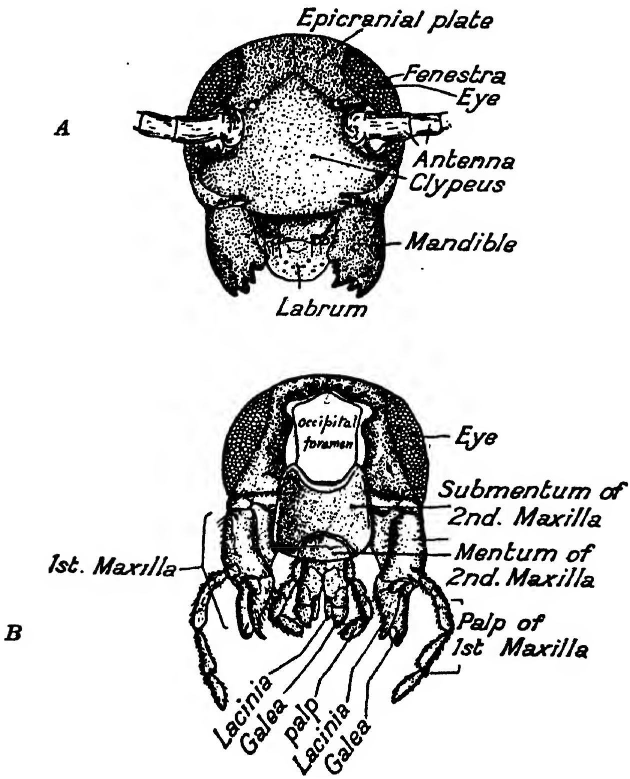


FIG. 29.
A. Head of cockroach (front view). *B*. Head of cockroach (from behind).

gut region. Other peristaltic movements are to be seen at the hind-gut end of the alimentary canal. Here may be seen, not only irregular downwardly progressing waves for the ejection of waste food, but a series of regular rhythmic contractions which pass forwards and are probably associated with another function.

Note.—It will be evident that the digestive organs are much more simple here than in any of the cases previously studied. Yet the essential character of digestion is the same; the action of enzymes produced by cells of the alimentary canal upon the food particles whose passage through the digestive tract is the result of peristalsis. Independent organs like the liver or pancreas are not present in Daphnia.

The cockroach

The mouth of the cockroach lies between an upper and a lower lip; the former (**Labrum**) is a projection of the fore part of the head, a fold of chitin; the latter (**Labium**) consists of two appendages (**2nd Maxillae**) partially fused

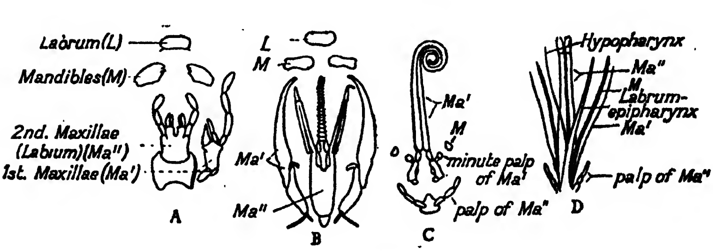


FIG. 30.—Diagram illustrating comparative structure of mouth parts in: *A*. Cockroach or beetle. *B*. Bee. *C*. Butterfly. *D*. Mosquito (female).

together. At the sides of the mouth lie a pair of **mandibles** and a pair of **1st Maxillae.** These are the characteristic mouth appendages of the insects. Their arrangement in the cockroach will serve as the basis for a study of the bee and the house fly.

Examine mounted preparations of the mouth parts of these insects (see page 92). The following section should be read in connection with the dissection of the cockroach.

outh pendages ckroach

The two mandibles are so fixed that they move from side to side; their edges are jagged and fit into each other, where they meet in the middle line. The 1st maxillae consist of several joints, as indicated in the sketch (Fig. 29). They are divided into two parts which are used to push the food into the mouth. The lower lip is obviously made up of two appendages not unlike the 1st maxillae.

The **Hypopharynx** or **Lingua** (not shown in Fig. 29) is a fold of chitin on the mouth surface of the 2nd maxillae.

The chief rôle in the intake of food falls to the mandibles and 1st maxillae. The chewing is performed by the mandibles alone, the 1st maxillae function more as organs holding the food in place and lead it to the mouth. Probably the maxillary palp is an organ for the sense of touch.

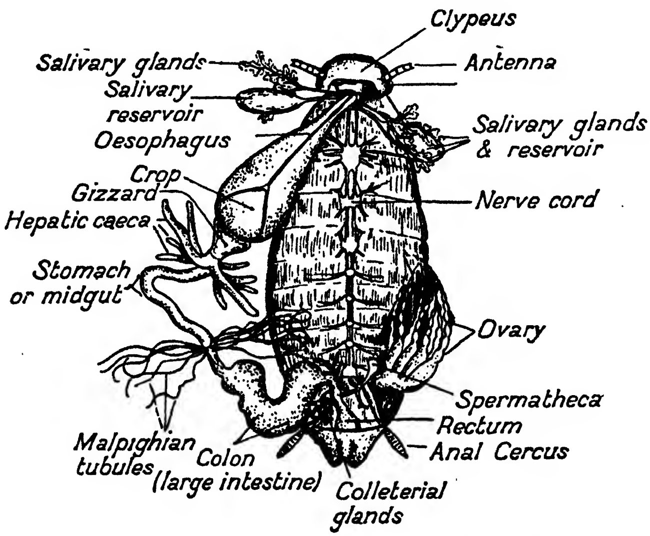


FIG. 31.—Anatomy of cockroach (female). (After Shipley and MacBride.)

(In some insects (white ants) the mandibles are capable of attacking the hardest of wood, and even the lead coverings of cables have been pierced.)

Food of cockroach

The cockroach, of which several species are known, may be regarded as one of man's domesticated animals. Unlike most insects it is an omnivorous feeder, taking vegetable as well as animal matter. Paper, woollen clothes, sugar, cheese, bread, meat, fish, leather, bodies of comrades, its own cast off cuticles and even ink are partaken of, and beer is relished.

In all probability some of the juice from the salivary glands of the cockroach passes out from the mouth opening

and moistens the food whilst it is being chewed. Well-developed salivary glands are present with reservoirs and paired ducts which fuse into a median duct opening into the mouth (see Fig. 31) on the hypopharynx.

Alimentary canal of cockroach

From the mouth a narrow gullet leads to a large swollen region, the **Crop.** Following this is a smaller chamber, the **Gizzard,** whose muscular walls bear six hard teeth within it. The **Mid-gut** lies behind the gizzard, and at its commencement it bears seven or eight blind tubes, the **Hepatic Caeca.** A large number of much finer **Malpighian Tubules** at its termination belong to the hind-gut; these are excretory organs.

The Crop and Gizzard and the hinder portions of the alimentary canal (Colon and Rectum) are lined by cuticle like the corresponding parts of the crayfish, so the secretion of digestive juices can only take place in the Mid-gut.

Digestion

Digestion of the food begins with its mixture with the salivary juices, which have been found to digest starches but not proteins. The saliva is therefore rather like that of the mammals in its action.[1] This starch digestion goes on whilst the food is lying in the extensible crop. The digestive juices from the posterior parts of the alimentary canal also enter the crop, and this recalls the conditions met with in the crayfish, where protein digestion commenced in the chewing stomach. The crop is in fact probably the chief seat of digestion.

The Mid-gut provides a very complete set of enzymes in the cockroach and various types of carbohydrates, fats and proteins can be digested. This is in keeping with the omnivorous habits of the animal.

The gizzard possesses quite a complicated inner wall, its lining being folded and thickened to form teeth. Straining pads with bristles are also present. The function of the gizzard is probably merely the mechanical one of stirring up the food and digestive ferments (not to bite up or break hard parts) and to act as a strainer.

In the cockroach, despite the cuticle lining, it is believed that a

[1] The salivary glands of other insects may have other functions—the cockroach only is being considered here.

slight absorption of fats takes place through the wall of the crop. The chief centre of absorption is, however, the Mid-gut, which as we have seen has also provided the digestive juices.

The protein-digesting enzymes are on the whole like the pancreatic trypsin of vertebrates. It must be noted here that the secretions of the Mid-gut in insects vary considerably with the habits of the species, and there are special enzymes like those which can digest wax (in the bee moth) and Keratin (in the clothes moth).

The so-called hepatic caeca should perhaps be regarded merely as extensions of the wall of the mid-gut. The walls of all these parts produce secretions and all partake in absorption.

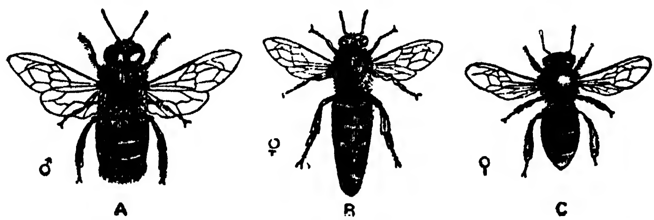


FIG. 32.—The honey bee.
A. Male or drone. *B*. Female or queen. *C*. Sterile female or worker. (From Borradaile.)

The *intestine*—colon and rectum. These posterior parts of the alimentary canal probably play little or no part in absorption, but simply convey waste matter to the exterior. The absorbed food probably reaches the various organs of the body by way of the fluids in the body cavity, as there is practically no system of blood vessels developed for the purpose of transportation in the Insecta. Reserve stuffs are frequently stored as fat; cockroaches are often found crammed with a special form of fat lying in the body cavity.

The feeding habits of the bee are such as to make the insect of particular interest, because the formation of honey is the direct result of these habits. The contrast with the cockroach is most marked, for the food is not only restricted to vegetable matter, but to only one form of it. This is in contrast again with the wasps. The sources of the bees' The honey bee

food are pollen and nectar collected from flowers. These substances are collected by the worker bees (see Chapter XVI), and out of them a series of foods are prepared for the use of the young, for adults at work in the nest, and for storing as reserve material.

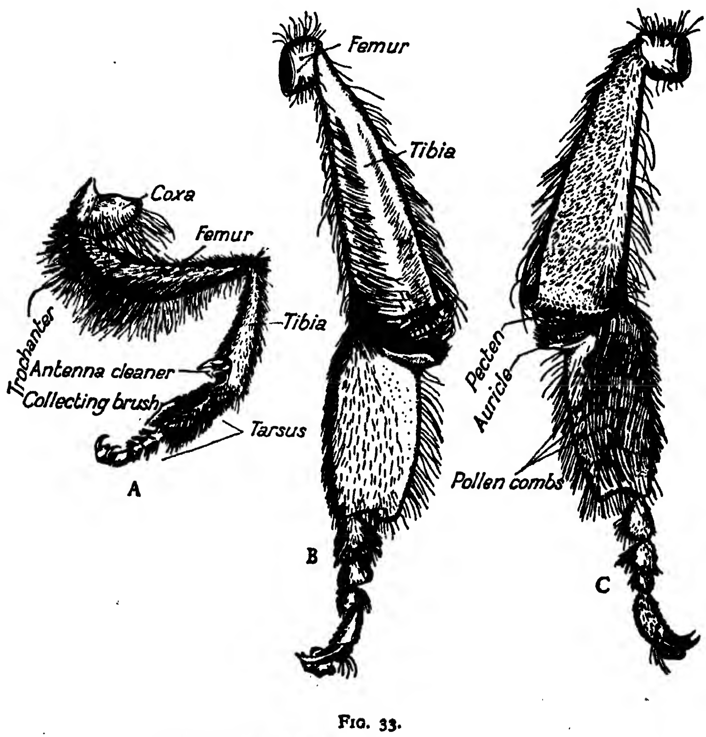


FIG. 33.

A. Left fore leg of worker.
B. Outer surface of left hind leg of worker.
C. Inner surface of left hind leg of worker. (After Casteel.)

Practical work Specimens of worker and other bees should be examined, and the legs and mouth parts mounted and compared. The worker bee should be dissected (see Figs. 33, 34, 35 and 52).

Food of the bee The Pollen is the source of the bee's protein, *i.e.* nitrogenous food, and special structures for collecting and holding it (termed **Pollen Baskets**) are found upon the legs of the **Worker Bees** (see Figs. 33 and 34). On the return

to the hive this pollen is scraped off with the aid of the mid pair of legs, and other worker bees compact the pollen together and store it into the cells. Pollen may contain as much as 30% of protein. Nectar is solely carbohydrate foodstuff.

The **Queen Bee** is specialised for egg laying, and consequently she has to be fed. Apparently the ordinary bee food will not suffice, and it has to be partially digested for

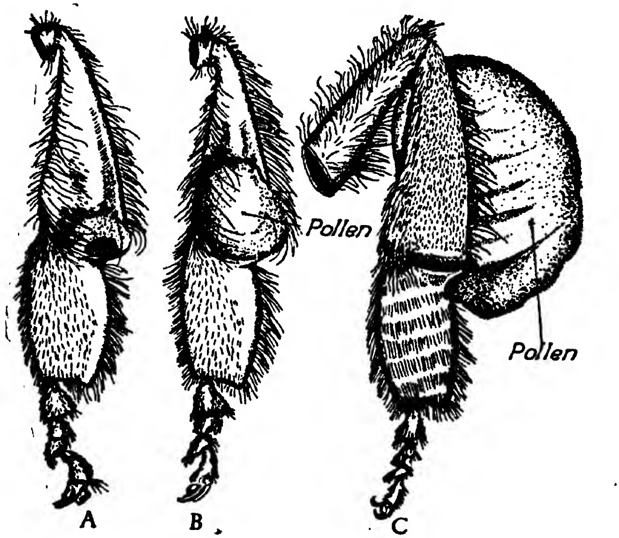


Fig. 34.—Hind leg of worker bee, showing how pollen is collected and carried. (After Casteel.)

her by the workers. Both the queen and the drone bees are unable to digest pollen, and they receive it in a partially digested state. Young bee larvae are still more restricted in diet, and apparently they not only require specially prepared foods, but the sexes are differentially cared for in this respect. The queen larvae receive a special food-juice for six to seven days.[1] The young male and worker larvae also receive this juice up to about the fourth day, after which an admixture of this with raw materials and honey is given. The differences are largely related to the

[1] This is the substance sometimes called Royal jelly or brood food.

amount of protein. They are indicated by the following table:

PERCENTAGE OF PROTEIN, FAT AND CARBOHYDRATE IN DRY WEIGHT OF FOOD RECEIVED BY THE DIFFERENT TYPES OF BEE LARVAE.

	QUEEN LARVA.	DRONE LARVA.			WORKER LARVA.		
		Up to 4 days' stage.	After 4 days' stage.	Average.	Up to 4 days' stage.	After 4 days' stage.	Average.
Protein	45·14	55·91	31·67	43·79	53·38	27·87	40·62
Fat	13·55	11·9	4·74	8·32	8·38	3·69	6·03
Sugar	20·39	9·57	38·49	24·03	18·09	44·93	31·51

Honey is a mixture of approximately the following composition: Water 20%, Invert Sugar 73%, Cane Sugar 1·75%, Ash 0·25%, and small quantities of other substances, including Malic and Formic Acids and traces of essential oils from the flowers. It is manufactured by the bees from **Nectar,** the composition of which is very roughly: Water 75·5%, Grape Sugar 12·3% and Cane Sugar 12·0% (as a matter of fact, the proportions vary). The method is described later.

Mouth parts of honey bee

The mouth parts of the bee are primarily adapted for sucking. Biting parts (the mandibles) are well developed, but are not used for biting. Amongst other functions, they are used for kneading the pollen and the preparation of wax. The sucking apparatus is very complicated, and consists of the lower lip (comparable to the lower lip of the cockroach) greatly elongated and modified. On each side of it is a process, the **palp.** This structure is sheathed on each side by the 1st maxillae. Out of these parts lying side by side and over each other a tube is formed (see Fig. 30) which communicates with the mouth opening.

Alimentary canal of honey bee

The bee possesses a most complicated set of salivary glands, the secretions of which probably perform more than one function. It is certain that an enzyme is produced here which *inverts* cane sugar, that is, changes it into a mixture of glucose and fructose.

Other enzymes play a part in the production of bee-bread from the pollen, and it appears that the salivary glands form the 'royal jelly'. The nectar obtained from flowers is forced by peristaltic movements from the pharynx

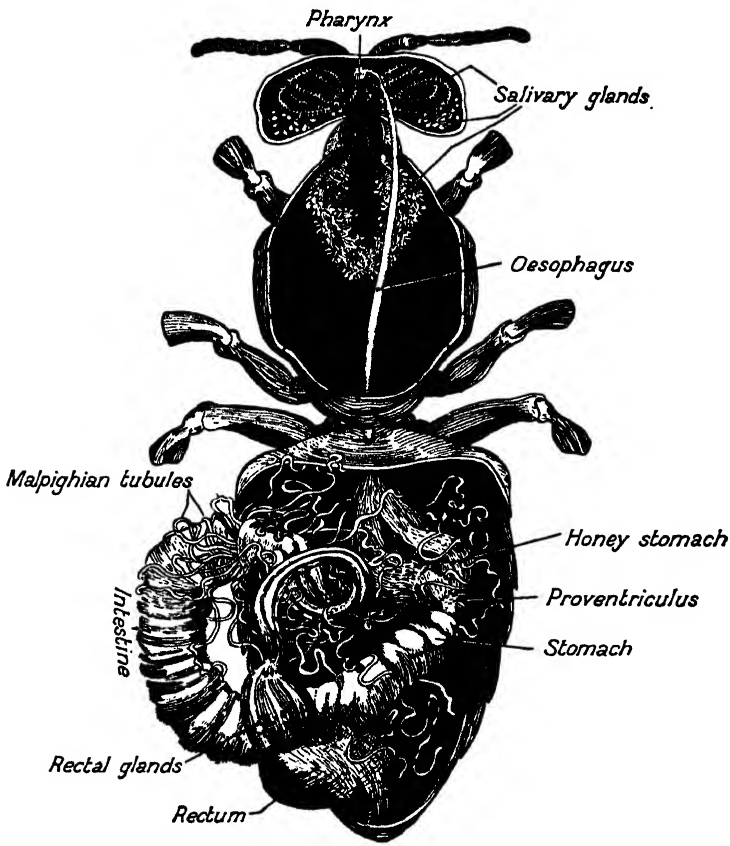


FIG. 35.—Alimentary canal of honey bee. (From Snodgrass.)

through the oesophagus into a chamber known as the **Honey Stomach.** (This corresponds to the crop of the cockroach.) It is followed by the 'Stomach' or **Mid-gut,** but the short canal connecting this with the honey stomach (Fig. 35, Proventriculus) probably corresponds to the gizzard of the cockroach (see Fig. 31).

The honey stomach

The honey stomach can be completely shut off from the mid-gut by a valve-like arrangement, and this is peculiar and important *because the food which enters the alimentary canal up to this point is not necessarily food for the bee itself.* This is a kind of communal digestive system used for the good of the bee society! The mouth for the individual bee might be said to be *behind* the honey stomach.

By the aid of complex movements of the alimentary canal it is possible for food to enter the mid-gut via the Proventriculus without actually entering the honey stomach (see Fig. 36 to explain this). The function of

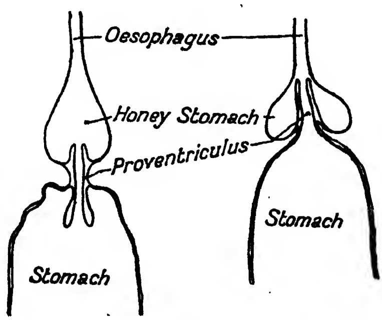


FIG. 36.—Diagram showing how entrance to stomach can be pushed forward so that food may pass into stomach without mixing with contents of honey stomach.

the honey stomach is the manufacture of honey. It is here that the nectar collects and is changed by the action of the saliva. It then passes back through the mouth and is stored in the combs for use.

Note.—Bee-bread, another food, is either a mixture of pollen and honey or it is pollen after chewing and admixture with certain juices of the salivary glands.

The mid-gut is the region where digested food is absorbed and possible further digestion takes place. There is still doubt, however, about the digestive juices of this part of the adult bee's alimentary canal.

Take the heads of 25 bees killed with ether and crush in a mortar with 10 c.c. of distilled water. Add a drop of toluol. Filter. Add some of the solution (1%) to 2 c.c. of pure 1%

Cane Sugar Solution (this must be tested for purity, and it must *not* reduce Fehling's fluid). After one hour test with Fehling again. The invertin in the bees' salivary glands will have split the cane sugar into glucose and fructose, the change which takes place in the honey stomach of the bee.

The house fly

The mouth parts of the house fly (see Fig. 37) are adapted only for sucking up liquid food. The insect cannot bite or pierce (like the mosquito). The sucking tube is known

FIG. 37.—Tongue of fly. (From Dakin's *Elements of Animal Biology*.)

as the **Proboscis** and is formed of the lower lip or **labium,** which has a deep groove on its upper surface in which lie the **Hypopharynx** and the upper lip. Mandibles are missing altogether and the maxillae are quite rudimentary. At the end of the lower lip are two very prominent little flaps which can be spread out or brought together—the **Oral Lobes**—and these form a kind of heart-shaped sucking expansion. The under surface, which is applied to the food, has numerous open grooves running outwards, and since these little gutters are supported by semicircular

thickenings of chitin they look almost like tracheae (the breathing tubes of an insect) when seen in microscopic preparations, and they are actually called **Pseudotracheae**; of course they have nothing to do with tracheae in any way. The whole proboscis can be folded up (drawn in) or outstretched.

Practical work (house fly) Kill house flies with a drop of chloroform on cotton wool. Mount the proboscis. It may be examined (with a low magnification) embedded in glycerine, but for the best results the head should be gently boiled in 2% caustic soda solution. After thoroughly washing, remove the proboscis, dehydrate in alcohol, and mount in canada balsam in the usual way. House flies are best dissected after fixing in paraffin wax and removing the dorsal surface carefully with very sharp scalpels made from gramophone needles.

Feeding habits of house fly Food is sucked up by the action of a powerful suction pump—the **Pharyngeal Pump.** Although flies can only suck up food in solution, they can bring certain dry foods (which are soluble) into solution by extruding saliva, and for this purpose the system of gutters at the end of the proboscis is specially adapted. It is in this way that a fly feeds on a piece of lump sugar. There are two pairs of **Salivary Glands** and the ducts open into the mouth. Food passes from the pump through the oesophagus to the **Proventriculus.** There is, however, a **Crop,** which is a blind tube arising from the lower side of the oesophagus. This crop is filled first when the insect is feeding. Consequently if the animal is disturbed it may move off to a quieter place and digest the substances taken into the crop by passing them forwards and then into the stomach. The fly may regurgitate the crop stores outside the mouth altogether; fly spots on windows, etc., are not always excreta of the house fly, but regurgitated food from the crop.

Observe the action of flies feeding on lump sugar. Note the movements of the proboscis and the act of extruding saliva.

Tape-worm and Ascaris Both these worms live in the stomach and intestine of

man and other animals in the midst of food which is being actively digested. It might be thought impossible for an animal to live in juices destined to digest almost any kind of animal tissue.

The nutrition of parasitic worms

The Tape-worm (see Fig. 226) has no digestive tube at all; *Ascaris*, however, has a mouth and complete alimentary canal. The tape-worm absorbs its food from the already digested food surrounding it—its outer surface is its absorbing surface. It is probable (although not quite certain) that the tape-worm is quite incapable of digesting food lying outside it, and that it depends entirely on food already digested by the host. *Ascaris* also feeds upon the contents of the alimentary canal of its host, but it utilises an alimentary canal which is very simple in structure. Digestive enzymes are secreted here, and digestion and absorption take place.

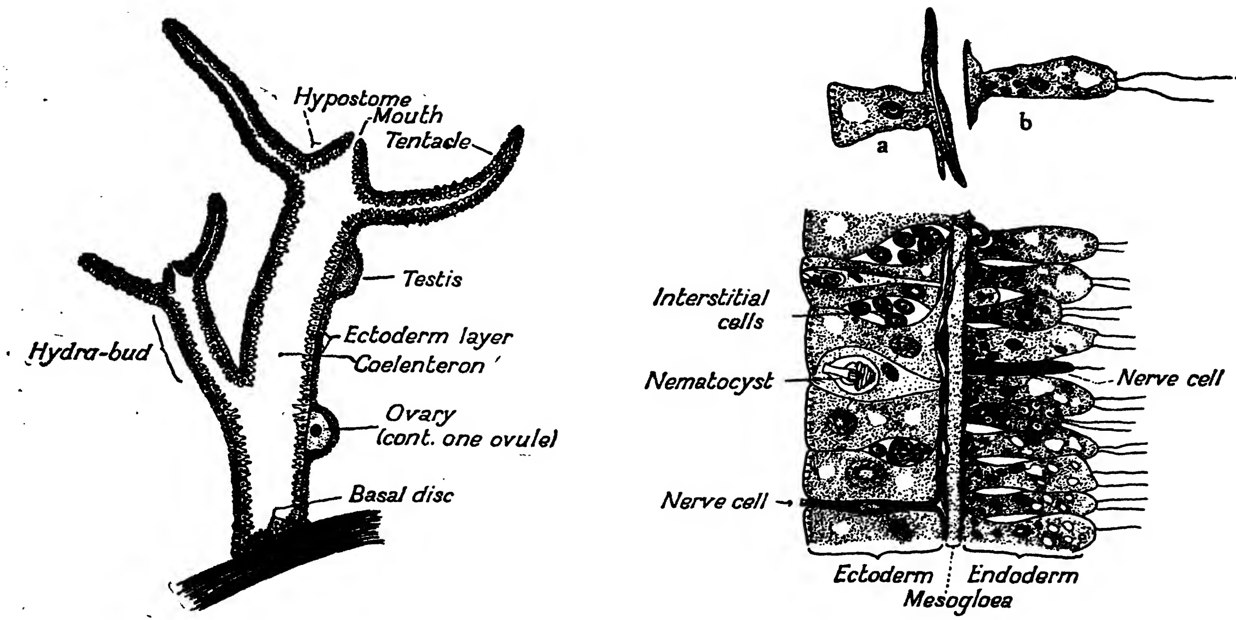
It will be seen that the tape-worm is more specialised than *Ascaris*.

Both these worms must have some mechanism by which they are protected from the action of the digestive juices of the host. Possibly it is a secretion like the anti-pepsin which prevents the gastric juice in the human stomach from digesting the stomach walls.

Antiferments of Ascaris and Taenia

Grind up about fifty fresh specimens of *Ascaris lumbricoides* (obtained easily from abattoirs) in a mortar with clean quartz sand. Make up to 150 c.c. with distilled water and add 1 c.c. Toluol. Allow to stand, then decant. Add 5 c.c. of the fluid to each of a number of tubes, some containing 5 c.c. of 1% trypsin solution, others with 5 c.c. of 1% pepsin solution (the former should contain about 2 c.c. of 0·4% Sodium Carbonate solution, and the latter about 1½ c.c. of 0·4% HCl solution as for digestive experiments) (see page 66). Set up controls containing no worm extract. To each tube add a small piece of fibrin. No digestion will take place in the tubes containing the worm extract. Some antagonising substances have been extracted from the worms which prevent the trypsin and pepsin from acting.

The lowest of the multicellular animals to be treated as a type is *Hydra*, the little fresh-water organism which is a representative of the class to which the Anemones, Zoophytes and Jellyfish also belong.



I

II

FIG. 38.—I. Diagrammatic section of *Hydra*. II. Section of wall more highly magnified. (*a*) Ectoderm cell, (*b*) Endoderm cell showing muscular basal processes. (After Schultze.

Hydra

In this organism (see Fig. 38) there is no alimentary canal, but the animal itself only consists of a two-layered wall of cells surrounding an internal cavity (known in this group as the **Coelenteron**). Food is captured by the tentacles, and it is passed by them through the mouth into the central cavity of the animal. Living organisms form the chief food of this group, and it is extraordinary how large the animals may be which are devoured. *Hydra* feeds upon *Daphnia* and other small crustacea, worms, insect larvae

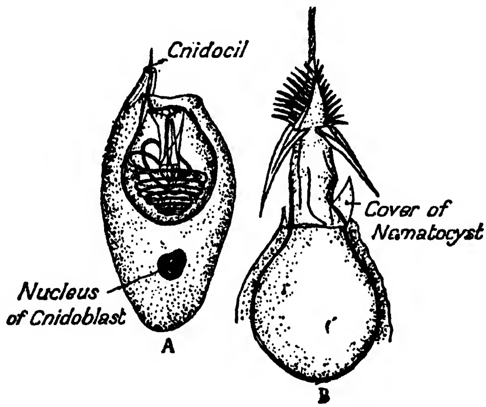


FIG. 39.—*Hydra* nematocysts.
A. Unexploded cnidoblast containing nematocyst.
B. Discharged cnidoblast.
(*B* is slightly more highly magnified than *A*.) (Modified after Schultze.)

(mosquito larvae in many cases) and even fish embryos.

Food capture by Hydra

These active creatures are not caught by the tentacles coiling round them, but by very extraordinary cells termed **Cnidoblasts,** which occur in the outer layer of the body wall and are especially numerous on the tentacles. Each cnidoblast (see Fig. 39) contains a little sac (the **Nematocyst**), one end of which is coiled up within the sac in the same way that a finger of a glove might be tucked in (one would have to imagine a glove with one enormously elongated finger). This long thread-like but really hollow process can be ejected violently; this takes place when a process of the cell (the **Cnidocil** or trigger) is touched by a living organism. If the thread does not penetrate the body of the prey, it may adhere to it or entangle it. A

little poison from the internal fluid of the nematocyst numbs the prey and the tentacles bring it round to the mouth. If it is too large to enter the cavity completely, part of it may project outside whilst the rest is being digested.

Digestion in Hydra

Digestion takes place not only in the cavity of the *Hydra*, but also within certain of the cells of the inner layer of the body wall which bound it. Amongst these cells two types may be distinguished—**Phagocyte Cells** and gland cells. The phagocyte cells actually feed like *Amoebae*, that is to say, they extend **Pseudopodia** and embrace particles of food which they take into themselves. This method cannot be applied to large prey, which therefore undergoes digestion in the coelenteron as the result of enzymes which are poured out by the gland-cells. These enzymes digest proteins most efficiently, and the fluid in the coelenteron is alkaline. No ferments for the digestion of fats are secreted in this way into the coelenteron, but particles of fats are taken up by the phagocyte cells. This also applies to particles of animal starch, i.e. glycogen. The first stage of digestion is, therefore, the partial breaking up and solution of the captured food in the coelenteron owing to the solution of the proteins by secreted enzymes. The phagocyte cells then take up partially digested proteins, fat particles and some carbohydrates and the digestion of these is completed within the cells. Undigested food is thrown out by the only aperture to the exterior—the mouth—through which it originally entered.

Practical work

Keep living *Hydra* in an aquarium with abundant Daphnids or other small crustacea, and note methods of food-capture and digestion. Make preparations and study the animal in accordance with directions given on page 365.

VI

RESPIRATION AND RESPIRATORY ORGANS

In the chapter on Nutrition it was pointed out that all living organisms require a supply of energy. This applies not only to the whole animal, but to every part which is built up of living tissue. That an actively moving animal or a muscle performing work requires energy is of course obvious, and it is not surprising that a gland which is actively secreting should require energy also. It is equally true of all living protoplasm.

Now, with few exceptions, the energy required for the different needs of the organism is ultimately derived from the combustion, or oxidation, of the substances of the body. The result might be expected to be the production of heat, just as when fuel is consumed in a furnace. Probably heat production is the rule, but it cannot always be observed, for the heat is converted into other forms of energy, and only in a few groups of animals do we find that the temperature of the body becomes appreciably higher than that of the surroundings.

Oxidation will not take place without the presence of the chemical element Oxygen, and just as we have seen that energy is required by every living cell, it is also necessary that oxygen should be available to every cell. The air (essentially a mixture of 79 parts Nitrogen, 21 parts Oxygen with traces of Carbon di-oxide and other substances) is the source of this oxygen; even aquatic animals obtain their supply from air, which becomes dissolved in the water in which they live.

In Aquaria, where the water supply is limited and its dissolved oxygen is soon used up, it is necessary to blow a

constant stream of air into the water to replenish supplies. (*Note.*—1000 c.c. of fresh water contain about 7 c.c. of oxygen, 15 c.c. of nitrogen and small quantities of carbon di-oxide dissolved in it.) Again, at high altitudes, where the air becomes rarefied, the amount of oxygen available is not concentrated enough to sustain active existence, and thus, in attempting to climb to the top of Mount Everest, oxygen has been supplied and carried in compressed form in cylinders on the backs of the climbers. (It is astonishing how the human body can adapt itself to the small supplies of oxygen present at high altitudes, and so much so that it is sometimes questioned whether the weight of oxygen containers does not counteract the benefits of the extra oxygen available.)

The activity of the body which comprises the intake of oxygen is usually known as breathing, but the complete process, **Respiration,** is much more than this.

It has been found that the chief source of energy in the living organism is the oxidation of carbon compounds. This combustion ultimately results in the production of carbon di-oxide and water, although the process does not take place in one step nor are these the only products. The entrance and exit of oxygen and carbon di-oxide respectively being generally associated, respiration is often merely regarded as the intake of oxygen and the output of carbon di-oxide at the body-surface. The ratio of the two, that is, the carbon di-oxide output to the oxygen intake, is termed the **Respiratory Quotient.**

Whilst breathing is one of the most characteristic and obvious signs of life, centuries passed before the chemical changes taking place were understood. It was not until the time of Black and Priestley (1755-1774) that it was discovered that oxygen disappears and carbon di-oxide is given off in breathing.

In the case of a small and simple organism like *Amoeba, Paramecium* or *Euglena,* the oxygen dissolved in the water easily passes through the cell wall to the protoplasm and the waste products of oxidation just as easily pass out. Respiration is then a simple diffusion of oxygen inwards

and carbon di-oxide outwards. In the higher animals, where the body is built up of myriads of cells closely packed together, it is obvious that this diffusion of oxygen from the outside would be a matter of some difficulty. Moreover the outer body wall is often impervious to the passage of substances through it, either from without or within. The consequence is that accessory organs are required, which are specially adapted to absorb oxygen in large quantities from the outside medium and to hand it on to fluids within the body which circulate it to all parts.

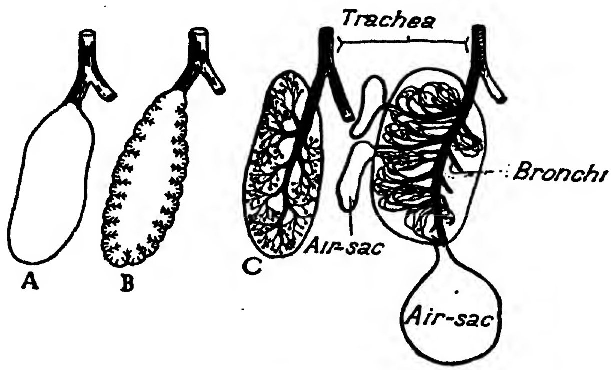


FIG. 40.—Diagram of lung structure.
A Amphibian lung with simple cavity.
B. Frog lung. *C*. Mammal. *D*. Bird.
The arrangement of the bronchi in the bird's lung is only suggested by the diagram.

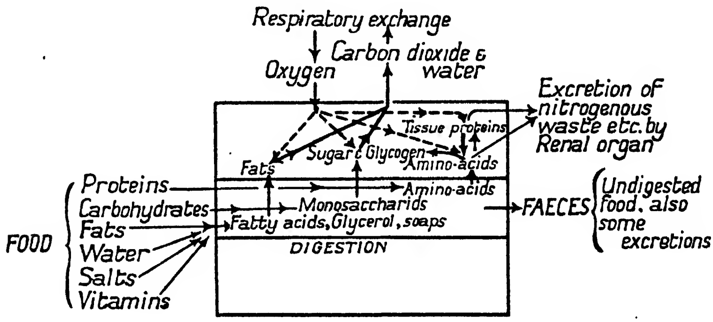
Similarly carbon di-oxide is carried back and passed out by the same path. These organs are known as **Respiratory Organs**. They are simple devices for an efficient exchange of gases between the body fluids and the surrounding medium, and the best known types are the **Lungs** (adapted for animals directly in contact with the air) and **Gills** (usually developed on animals which live in water).

The circulation of the oxygen and carbon di-oxide in the body is one of the functions of the blood and the blood system, the development of which is correlated with the needs of the animal (see Chapter VII.).

In order to make it quite clear that respiration means more than the mere passage of oxygen into or through the

respiratory organs and the complementary outward movement of carbon di-oxide at the same place, this exchange is termed **External Respiration,** whilst the exchange within the body to the actual parts using oxygen is spoken of as **Internal Respiration.**

Before passing on to describe the different types of respiratory apparatus, it will be as well to crystallise our knowledge of the metabolic processes going on in the body by making a diagram to show what substances are taken in and what pass out.



Respiration in some small animals

It has been seen that the single-celled Protozoa do not need special respiratory organs to facilitate respiration. This also holds good for a number of small multicellular organisms, where the relation of surface area to volume is great and the body wall is sufficiently permeable for oxygen, and even for moderately large animals such as the worms (earthworm, for example) and anemones, in which either the body wall is a very efficient external respiratory organ or the amount of oxygen required is relatively small. The skin plays an important part in some highly developed animals such as the frog and other Amphibia and certain fishes, but speaking generally, for the higher animals the development of scales, hair and feathers greatly reduces or prevents such a function.

(Certain bacteria do not require oxygen at all—are even killed by its presence. They are known as Anaerobic organisms. They require energy, but this is obtained as a result of other chemical reactions. Anaerobism is rare amongst

animals, but it is found in some cases. Certain worm parasites of the intestine (tape-worm) can live without oxygen and some shellfish for a time at least.)

Respiratory organs are as a rule structures where either by folding or by other means a great increase is obtained in the area of a surface which is very suitable for the diffusion of oxygen and carbon di-oxide. These surfaces are well supplied with blood capillaries in such a manner that there is but little tissue between the blood flowing in the vessels and the external medium. Respiratory organs are usually extensions of the outer layer of the body (ectoderm). These extensions may be produced by outgrowths or by ingrowths. The first type is characteristic of aquatic animals (and results in gills), the second type is characteristic of air-breathing animals (and results in the breathing tubes of insects and the lung books of spiders). The lungs of vertebrate animals are bags developed from the alimentary canal, and are somewhat different from the respiratory organs of the lower types. **Respiratory organs and mode of operation**

Whether the respiratory organ consists of an internal cavity or a more or less sheltered nook on the exterior of the body where the gills lie, it must be obvious that some arrangement will be necessary to keep the external medium moving. In a lung the oxygen will speedily be taken from the air and a fresh supply will be required ; similarly the oxygen in the water in a gill chamber will soon be exhausted. This means that with the development of respiratory organs there must be a mechanism (simple or complicated according to the demands) which serves the purpose of bringing fresh supplies of air or water to the specialised respiratory surface. Let us now glance at some examples, and then we may discuss further the action of the blood.

Lungs are characteristic of all vertebrates, from the Amphibia upwards. They are developed from the endoderm wall of the alimentary canal (and in this are rather exceptional, for respiratory organs are characteristically ectodermal, that is, derived from the external cellular layer of the body-wall). Essentially they are a pair of elastic bags, whose internal highly vascular wall is usually **The lungs**

greatly increased in area by infolding, so as to form countless chambers. This complicated folding has arisen gradually; the lungs of the frog are comparatively simple bags, compared with the lungs of the birds and mammals, those of birds being especially modified. The apparatus for filling the lungs with air also differs considerably in the frog, bird and mammal. The illustration (Fig. 40) shows the nature of the lung structure in these groups. In the Amphibia and reptiles one can speak of a cavity much divided up by walls.

The opening from the pharynx into the air passages is known as the **Glottis.** It is usually slit-like (see Fig. 21) and can be closed or opened by muscles. From the glottis the windpipe or **Trachea** conveys the air to the lungs. At the upper end of the tube the **Larynx** is developed. In the mammals this is a highly developed organ, consisting of cartilages supporting the vocal cords, and in man capable of producing that wonderful range of tones from the sonorous bass to the bird-like notes of a Tetrazzini. The larynx is very slightly developed in the frog and little better in reptiles and birds. The notes of birds are not produced by the larynx at all, but by a similar structure called the **Syrinx,** which, however, is found lower down where the windpipe divides into two branches.

The trachea eventually divides into two branches known as **Bronchi,** and it is these tubes which sub-divide on entering the lungs in the higher vertebrates.

In the mammals the sub-division has gone so far that we have a mass of greatly ramifying bronchial tubes, whose finer branches, known as **Bronchioli,** terminate in little chambers called **Alveoli.**[1] These are the cavities where the first respiratory exchange takes place. The bird's lung is rather more complicated and perhaps more efficient. Suffice it to say that the air passes right through the bird's lung, through countless small tubules, and out again into

[1] To illustrate the characteristic enlargement of the area of surface provided with capillaries in a respiratory organ, it may be pointed out that in man there are probably about 700,000,000 alveoli in the lungs, and the combined area of their walls is supposed to be about 60 times that of the body surface—enough to carpet a room 30 by 35 feet.

large thin-walled chambers called **Air-sacs** which lie in the abdomen and in the thorax. The lung becomes almost a mass of what one might term air capillaries, between which are the blood capillaries. Respiration takes place in the lung as the air passes both inwards and outwards. There are no blind ending tubes in the bird's lung. The air-sacs

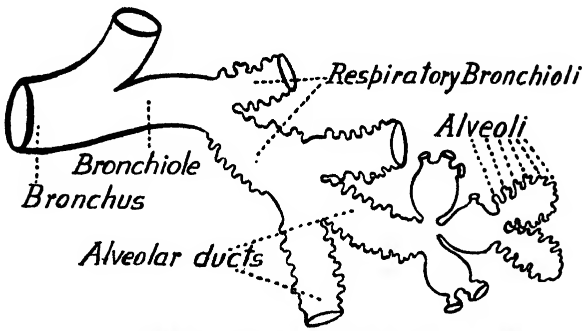


FIG. 41.—Diagram of bronchioles and alveoli in human lung.

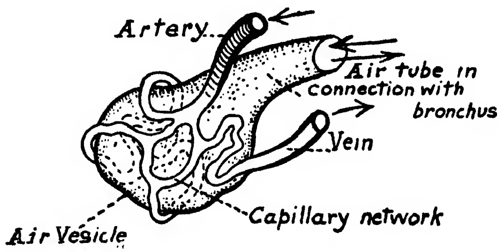


FIG. 42.—An alveolus from the lung with its blood vessels (highly magnified). (From Johnstone.)

play a part in renewing the air in the lungs (see below), but are not respiratory surfaces, and, as a matter of fact, their blood supply is arterial and they bear no respiratory capillary network. They extend everywhere between the viscera and the body wall and even have branches extending into some of the bones (the humerus in the wing, for example).

Mechanism for filling lungs with air

In the mammal, man for example, the lungs are filled with air by suction. The lungs lie suspended in two cavities (pleural cavities, see Fig. 44) in the thorax, the wall of

which is supported by the ribs. The thoracic cavity can be enlarged by (*a*) raising the ribs, which are hinged obliquely to the backbone, and (*b*) downward movement of the diaphragm, a muscular partition which separates the cavity of the thorax from that of the abdomen. When this takes place air rushes into the lungs in order to fill the cavity in which otherwise the pressure would be greatly lessened. The depression of the ribs and the raising of the diaphragm

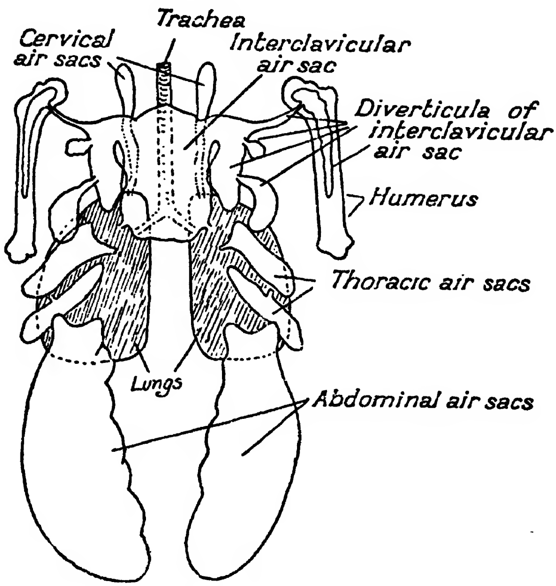


FIG. 43.—Diagram of air sacs of pigeon. (Modified after Heider.)

forces the air out. The force of entrance of air depends therefore on the muscular activity of the thorax wall and diaphragm and on the pressure of the air, whilst its exit normally depends on the thorax sinking back by its own weight and partly on the elastic nature of the lungs. A simple model made as in Fig. 45 explains the action better than detailed description. Owing to the elastic nature of the lungs, they are always tending to contract to a greater extent than is permitted by the size of the chest cavity. Thus there is always a tendency for a negative pressure in the thoracic cavities. If the thorax is perforated the lungs

collapse completely. This condition may be produced in the model by exhausting a little air from the glass chamber. It is conveniently performed by pushing up the indiarubber sheet with the small tube open and then plugging this with a bit of glass rod. By depressing the sheet of indiarubber, the lungs (or toy balloon may be used instead) fill with air; by pushing it up they are partially emptied. Pulling out the glass plug represents the perforation of the thorax wall in an accident, etc.

The Mammalia are the only vertebrate animals which possess a diaphragm. The birds whilst at rest use their

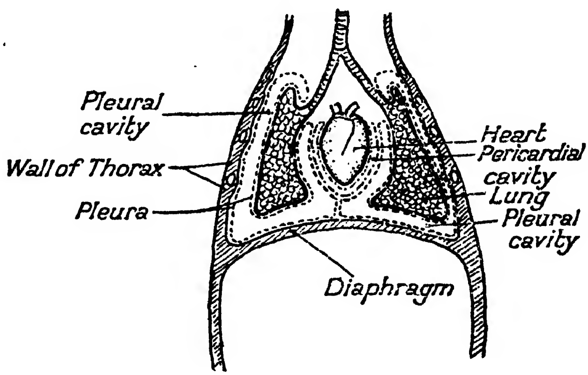


FIG. 44.—Diagram of thorax of mammal. (Modified after Jammes.)

ribs alone for increasing the capacity of the body cavity. The air sacs help in the suction of air, for when the body cavity is expanded air rushes through the lungs into them. When flying, however, the process is somewhat different, for the great flight muscles prevent the rhythmic rib movements of the breast bone. It has been suggested that by reason of the great speed of flight a stream of air passes through the nasal apertures through the lungs into the air sacs. This air is forced out at intervals by contraction of the abdominal muscles. There can be no doubt that the lungs are most efficient respiratory organs in birds.

[*Note.*—The air sacs are not structures to make the body of the bird of less weight in the air, a frequent misconception. One might regard the bird's lung proper as more essentially concerned with the gaseous changes between the air and the blood, whilst the air sacs are ventilators and storage regions.]

Respiration in frog

The respiratory function in the adult frog is not confined to the lungs, for the skin and the mucous membrane of the mouth are also active. The action of the lung will be taken first. The mode of entrance of air into the frog's lung is quite different from that seen in the types already described, for besides having no diaphragm the frog has only vestigial ribs. Instead of the air passing in by suction, it is actually forced in by the pump-like action of the mouth. As the

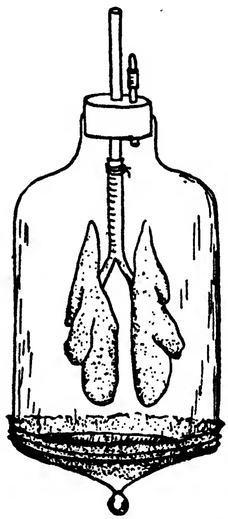


FIG. 45.—Experiment to illustrate expansion of lungs of mammal (see text).

method is frequently insufficiently described, a detailed account may be given here.

Watch a frog which has been calmly resting in a vivarium or other suitable container. Notice the rapid movements of the floor of the mouth (throat region). Time them. The mouth is kept closed throughout. At intervals of roughly a minute or more, note stronger movements accompanied by closure of the external nares (the nostril openings on surface of head) and pronounced movements of the sides of the body. Whilst the more frequent and regular movements of the mouth floor are taking place, the nostrils are kept open, and air passes into and out of the

mouth only. Whilst this is going on a respiratory exchange of oxygen and carbon di-oxide *takes place through the mucous membrane of the mouth,* which is thus acting as a respiratory organ. After a period (it may be a minute) the nostrils are closed and the floor of the mouth is strongly depressed. As a result of this special enlargement of the closed buccal cavity (aided by additional muscle action) air is drawn from the elastic-walled lungs into the buccal cavity, and thus mixes with the fresh air which had previously entered by the nostrils. This action is quickly followed by a forcible elevation of the mouth floor, the nostrils still being kept closed. The consequence is that the mixed air is forced back by the only open way, that is, through the glottis leading to the trachea, and this mixed air reaches the lungs. The nostrils are now again opened, and the rhythmical mouth respiration is repeated. It will be noted that the lungs are only filled at long and rather irregular intervals.

As both the entrance of air through the nostrils to the mouth as well as the forcible driving of the air from the mouth to the lungs depends upon there being only one path open when the floor of the mouth is raised and dropped, it is clear that the mouth itself must be kept shut. The closure, as a matter of fact, is remarkably air-tight. If a frog's mouth were kept forcibly open, the animal would actually die or at least show signs of asphyxiation.

The other method of respiration available to the adult frog is by exchange of oxygen and carbon di-oxide through the skin. It is necessary for this purpose that there be an adequate peripheral blood supply, that the skin be delicate and not covered with an impervious layer of scales, and that it be kept moist. All these features are characteristic of the frog's skin. The fact that respiration actually takes place can be demonstrated by keeping a frog in a bottle filled with water (naturally the water must be sufficient in volume to provide enough dissolved oxygen and must be changed if the experiment be kept going for some time). Under these conditions no lung or mouth-breathing can take place.

The frog can only obtain sufficient oxygen by this means if the temperature be kept low. Skin breathing is then an emergency measure for use under water, as also for respiration during the period of winter sleep when the frog is often submerged and the oxygen requirements are quite at a minimum (see Winter Sleep, page 161).

Respiration in fishes

Keep one or two goldfish under observation in glass aquaria (see page 475). Make dissections of dogfish and suitable bony fish (herring, mackerel or other fish in season).

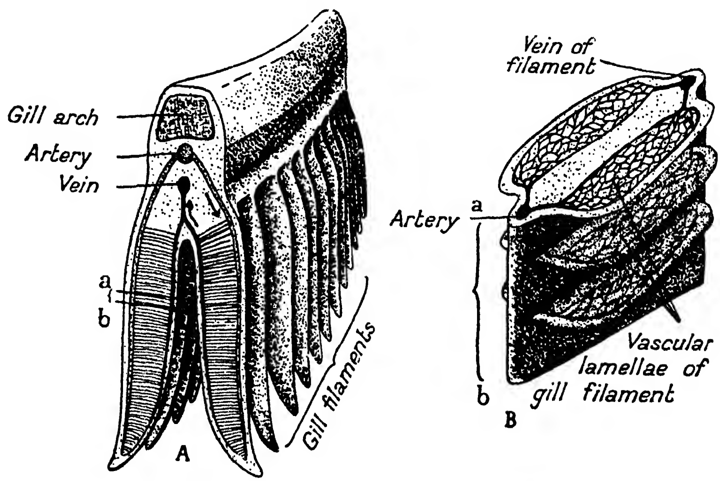


FIG. 46.—Diagram of gill structure of bony fish.
B is a more highly magnified view of portion of gill filament *ab* in *A*.
(After Goldschmidt.)

The respiratory organs of the fishes are characteristic of aquatic animals. They are known as gills, and are delicate folds or processes of epidermis which arise from the walls of slits or clefts (the gill clefts), which penetrate the sides of the pharynx and so put the cavity of the pharynx in communication with the exterior. Blood capillaries form a network on the delicate gill processes or platelets, and there is only the thinnest of tissues between the blood and the water which is caused to stream over the gills.

There are roughly two types of gills amongst fishes. Five gill slits are usually found on each side of the body. Between the slits there is of course a certain amount of

tissue which forms what is known as the **Interbranchial Septum.** Now in the dogfish and its allies (sharks and rays) the interbranchial septum is well developed, and so the slits are very clearly seen on the surface of the body. In other fishes a fold grows backwards over all the gill clefts, and forms a very conspicuous gill cover or **Operculum.** At the same time the interbranchial septum is so much reduced that the gills completely mask it.

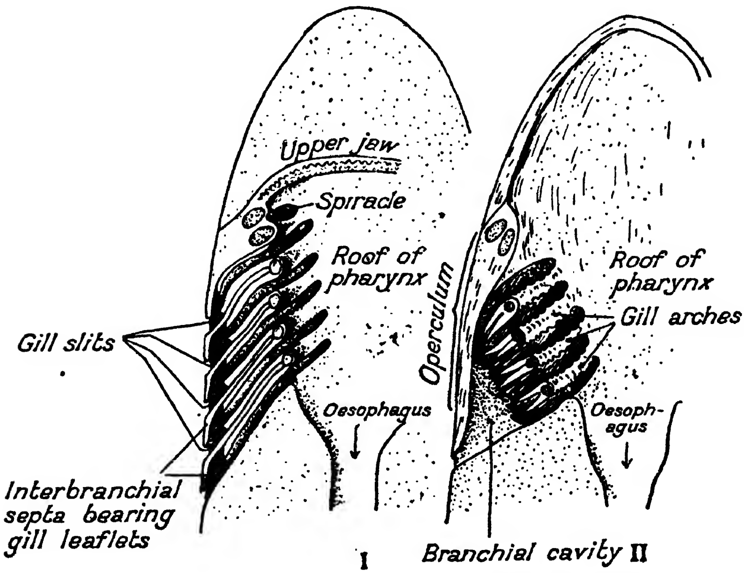


FIG. 47.—Diagram illustrating the difference between a dogfish (I.) and a bony fish (II.) in the gill region.
(The floor of the mouth and pharynx is supposed to be removed in each case.)

The illustrations explain these differences, and a superficial glance at a dogfish and herring will make the matter clear.

The actual mechanism of respiration is approximately the same in the different types, and we shall therefore confine ourselves to a bony fish such as the gold fish or the herring.

Water is taken in through the mouth and passes over the gills to the outside again. This current is kept up as follows. First the cavity of the mouth is enlarged through

the fish depressing the floor of the mouth. At the same time the mouth is opened. Water enters by the mouth to fill the enlarged space, and although some may enter under the operculum, this is practically insignificant, because the **Branchiostegal Membrane** (see Fig. 48) is forced like a valve against the side of the fish and closes the aperture. Following this, the mouth cavity is reduced in size and the water pressed out. It has to go over the gills and out under the opercula, because the mouth is closed and at the same time often guarded by a pair of valve-like folds (see Fig. 48).

Death of fish in air

It is often asked why fish die when lifted out of the water (and with all the signs of asphyxiation), seeing that the gills are brought into contact with the air, which is a more abundant source of oxygen than the water in which the fish lives. It cannot be that the gills dry up—this may take quite a little time after the fish are dead. One of the most reasonable explanations is that the *area* of the respiratory surface becomes at once very much reduced, because all the little gill fringes and platelets (see Fig. 46) which were supported in the water fall flat and lie upon each other. The gills are not adapted to aerial respiration. The reason that some fishes live longer out of water than others is to a certain extent bound up with their hardiness under these abnormal conditions. The eel, however, is able to use its skin as a respiratory organ, and consequently is rather abnormal in respect to longevity out of water.

The gill platelets are naturally extremely delicate structures, and it is this part of the fish which is affected first and very quickly when a fish is placed in abnormal fluids. Thus sea-water passing over the gills is deadly to most fresh-water fishes, and fresh water is deadly to marine fishes. Yet in some unknown way the eel and the salmon have adapted themselves even to these changes and can pass from fresh water to the sea or vice versa in a few hours.

Respiration in frog-tadpoles

The early stages of the frog are, as is well known, completely aquatic and fish-like. The tadpoles breathe by means of gills. There are, however, two successive gill-stages. The first gills to appear are feathery outgrowths from the

sides of the body (see Fig. 201), and in these there is the usual capillary circulation. The active movements of the tadpoles render it quite unnecessary to have special arrangements for circulating water over the freely exposed gills. Very soon, however, these gills are covered over by a fold of skin (Fig. 201) (an operculum reminding us of the bony fish conditions), and as they disappear, gill-slits arise in the walls of the pharynx. The membrane of the slit walls is modified in the characteristic way to act as gills, and thus the tadpole breathes like a fish. Water passes in through the mouth, through the gill-slits over the gills, and out under the operculum on the left side of the body.

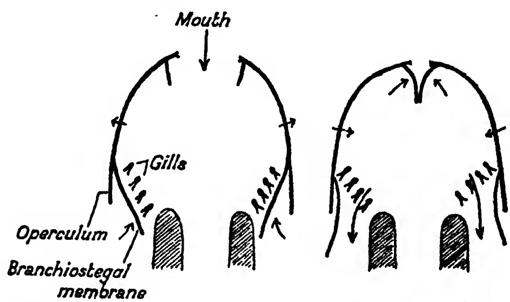


FIG. 48.—Diagram of movements of gill cover and mouth of bony fish during respiration.

Respiration in crayfish

The crayfish, lobster and crab are all characterised by the possession of gills, which function precisely as do the gills of fishes, but they are different altogether in position, and there is a different mechanism to ensure the continuance of a current of water, the respiratory current, over them. In the crayfish the gills are delicate branched structures, about eighteen in number on each side. They are attached, some to the bases of the thoracic limbs, some to the membranes joining these limbs to the body and some to the side wall of the thorax. All lie sheltered by a flap—a fold of the body wall—known as the **Branchiostegite,** which forms the outer wall of a gill chamber. Water is kept flowing through this chamber by the movements of the appendage known as the 2nd maxilla (see Fig. 245). Part of this structure (the **Scaphognathite**) acts as a baler and causes

water to move out forwards just below the antennae (the long feelers). Fresh water enters the gill chamber between the bases of the legs and follows the paths shown in Fig. 49.

Each gill has the structure shown in Fig. 50, and not only the shaft, but each of the little outgrowths is subdivided by partitions. A stream of blood passes up one side and down the other, and on its way it takes oxygen from the water and gives up carbon di-oxide. (See end of chapter for practical work.)

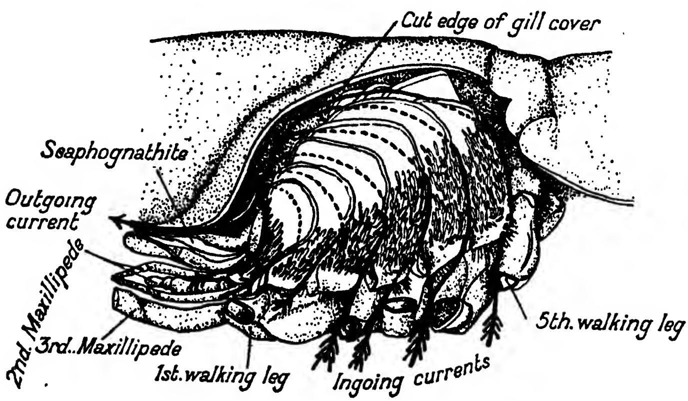


FIG. 49.—Gill cavity and gills of crayfish, showing direction of respiratory water current. (After Bock).

Daphnia and Cyclops (respiration) Most of the tiny Crustacea of the groups to which *Daphnia* and *Cyclops* belong have no special respiratory organs. Their external surface is sufficiently permeable by oxygen and carbon di-oxide, and its area is also sufficient for adequate respiration. In *Daphnia*, however, there are certain small processes of the appendages, which may sometimes be seen more distinctly if the living animal is kept in water to which a little very dilute solution of neutral red has been added.[1] These are very simple gills. The movements of all these animals are lively enough to keep the water constantly changed about them.

[1] Neutral red powder might be added. The resultant solution must be only wine-yellow in colour. This staining of the gills is not always successful.

Respiration in insects

The breathing apparatus of insects is highly interesting because, contrary to what is met with in almost all other groups of animals, the air itself is actually conveyed to the remotest tissues by means of an elaborate system of branching tubes called **Tracheae.** These usually open on the sides of the body, the apertures being called **Spiracles.** In some insects, however (more especially the aquatic young stages), the tracheae do not open on the surface in

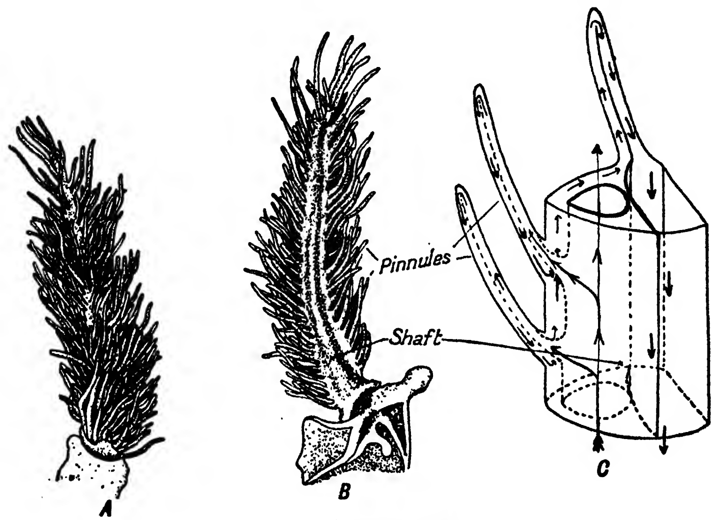


FIG. 50.—Gills of crayfish.
A and *B*. Two views of a gill.
C. Diagram of blood circulation in a gill shaft and pinnules.
(After Bock.)

this way by spiracles, but they form a closed system associated with skin respiration or with gills.

The spiracles are usually found between the segments and are guarded by bristles or hairs to exclude dust and other foreign bodies. They can be opened or closed by valves.

The bee, housefly and cockroach all have tracheae opening on the surface by spiracles ; the essentials of the system are the same in the three cases, although the details vary.

From the spiracle a short tube usually leads to a main tracheal trunk or a sac which runs along the side of the body and then gives off a system of branches which lead eventually to excessively delicate tubes called **Tracheoles.**

These form a network amidst the tissues, and their end portions contain a varying amount of fluid; it is probably by means of the tracheoles that oxygen is passed across to the cells. At certain places in the tracheal system great thin-walled expansions or *air sacs* may be found. They are probably air reservoirs for use during flight.

Tracheal tubes are highly characteristic in appearance, and in the freshly killed specimens they stand out as silvery threads owing to the enclosed air. Under the microscope they present a very characteristic structure.

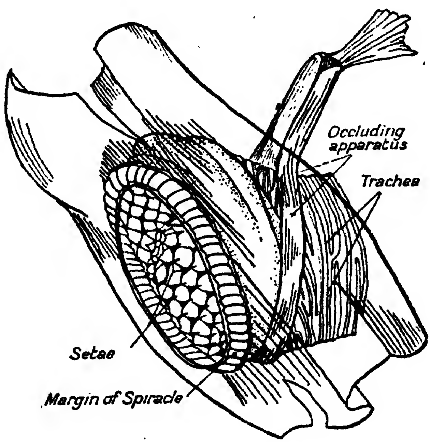


FIG. 51.—Spiracle of cockroach.

Each tube consists of a delicate layer of epithelium (continuous with the ectoderm of the body wall), within which is a delicate lining of cuticle (known as the Intima) continuous with the outer hard cuticular case of the body. The tracheae are in fact inpushings of the outer layer of the body. The most characteristic feature in their microscopic appearance is due to the chitinous lining being thickened at intervals in such a way that a spiral ridge is frequently formed. It looks as if a spirally coiled thread ran round the cavity just like the internal coil of wire used as a support in old-fashioned rubber gas-pipe tubing. Sometimes this thickening forms rings instead of a spiral. Usually both are absent from the large tracheae close to the spiracular

openings, and they are altogether absent from the fine terminal branches of the tracheae—tracheoles.

Movements of air into and out of the tracheae are brought about by rhythmic movements of the body, the dorsal and ventral walls of the abdomen being regularly approximated and separated. These movements can be observed in the

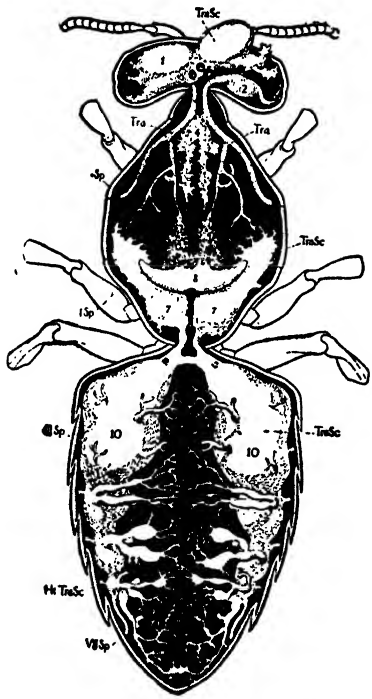


FIG. 52.—Air sacs and tracheae of bee. (From Imms after Snodgrass.) *Tra. Sc.*, Air Sacs; *Tra.*, Tracheae; *Sp.*, Spiracles.

living insect. In the dragonfly they are repeated 30-35 times per minute. There is some evidence for believing that a definite circulation takes place in the larger trachea; in fact, that air enters through the anterior spiracles (thoracic) and leaves the animal by the abdominal spiracles. The manner in which the air passes through the most minute branches of the tracheae is more difficult to explain.

Respiration in aquatic insects

Amongst the insects living in water some take up air from the atmosphere through their spiracles (the adult

water beetles, *Dytiscus* and relatives, for example). The mosquito larva also does this, but can abstract oxygen from the water also. Other aquatic insect stages, such as the larva of the Mayfly, Dragonfly and others, take up their oxygen entirely from that dissolved in the water.

Some of the most beautiful contrivances for respiration are found among aquatic insects. Since the water beetle,

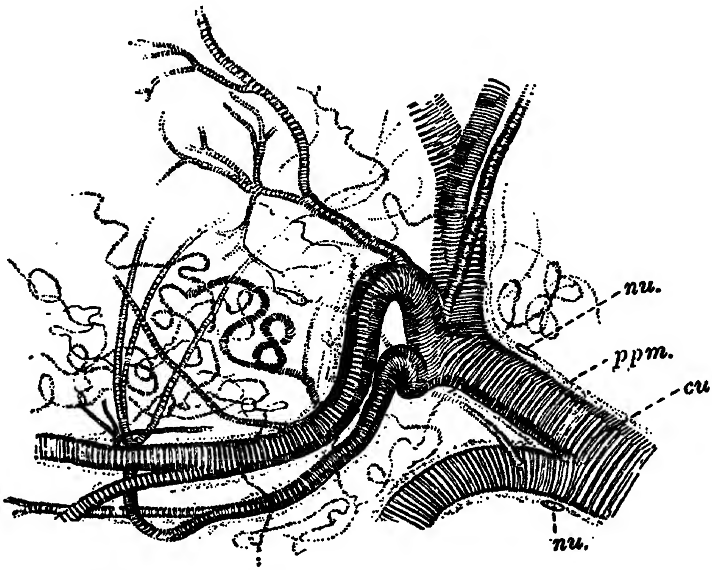


FIG. 53.—Portion of tracheal tissue of cockroach, magnified. (From Borradaile.)
cu., Chitinous lining with spiral thickening; *nu.*, nuclei of epithelial layer *ppm.*

Dytiscus, is entirely dependent on atmospheric air, it must come to the surface for it. It does this at intervals of about eight minutes. Floating to the surface with its tail end slightly raised, it pushes this end of its body into the air and raises the wing covers. The spiracles are uncovered and air passes into them. In addition to this, however, the air becomes trapped as it were between special hairs on the back of the abdomen, and thus, when the insect descends, it carries a bubble of air between its wing covers and its abdomen. This supply is drawn on when the animal is below. Another water beetle, the great water

beetle (*Hydrophilus piceus*), has an additional arrangement of hairs of a similar kind on its ventral surface, so that a ventral film of air is also carried down.

The opening of the tracheae of the larva of the mosquito and gnat is in a peculiar position—at the end of a special organ called the **Siphon** developed on the eighth segment of the abdomen (see Fig. 55). Two main tracheal trunks run along this and open at the same aperture, which is guarded by five little flaps. These serve to shut the breathing aperture when the larva sinks. Now it will be seen that the mosquito larva must come to the surface tail uppermost for air. It is held by the surface film, which it perforates with its siphon. At the same time, the head **Respiration in mosquito larva**

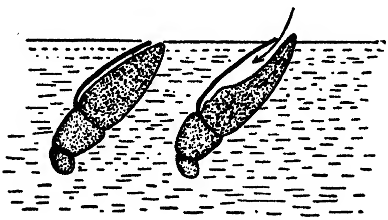


FIG. 54.—Diagram of Dytiscus breathing. (After Schoenichen.)

being undermost, it can go on feeding. When the larva descends it frees itself from the pull of the surface film (see Chapter XVIII) by closing the flaps guarding the siphon aperture and then sinks by its own weight. It is this mechanism which gives the sanitary officials one method of destroying mosquito larvae without draining water tanks or poisoning the water, for a thin film of oil floated on the surface of an infested water tank upsets the action of the respiratory organs, and breathing is prevented.

Many aquatic larvae have outgrowths from the body which, without experimental evidence, have been called 'gills'. Some of them are undoubted respiratory organs even if only accessory to other organs, but very considerable doubt has been thrown on this function in the so-called anal gills of the mosquito larva (see Fig. 55). It is suggested instead that they are chiefly water-absorbing organs.

In other insects some of these plate-like projections are very rich in tracheae and have been called **Tracheal Gills.** These are the chief respiratory organs of the Mayfly larva (Fig. 214) after the second moult. A number of leaflets are borne on the abdominal segments, and these are kept in movement by the insect.

Respiration of larval dragonfly

The larvae of the dragonfly also breathe by tracheal gills, but these are not situated in the same place in all species. In one group of dragonflies (the Anisoptera—

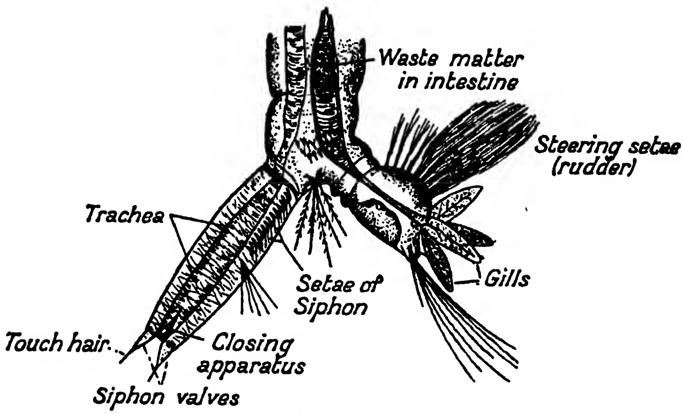


FIG. 55.—End segments of larva of a *Culex*. (After Raschke.)

see Fig. 56) the tracheal gills are actually within the rectum, and form what is known as a **Branchial Basket.** In other forms there are three external projecting leaflets (**Caudal Gills**) at the end of the abdomen. The branchial basket is a very complicated and efficient arrangement of little leaflets or folds arising from the walls of the rectum, which is wider and forms a special chamber at this point. Tracheal capillaries run in the tissue of the leaflets and connect up with the main tracheae. These rectal gills are bathed by water which is sucked in at the anal opening. Thus one finds special respiratory movements of the rectum which may easily be watched. Water is sucked in quickly and forced out slowly or quickly.

These rectal currents of water may be detected in the

larvae possessing caudal gills, although they are not so obvious. In this type, however, the caudal gills are the most efficient breathing organs. They each contain two main tracheae and a number of fine branches.

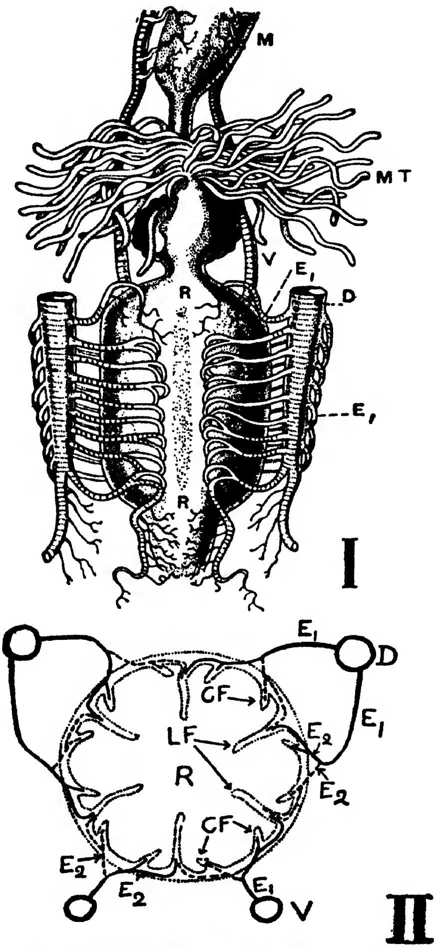


FIG. 56.—Branchial basket of a dragonfly larva. (From Imms.)
I. Rectum showing tracheal supply. II. Transverse section of rectum showing gill folds of rectal wall (*LF*)
D, Tracheal trunk; E_1 and E_2, smaller tracheal branches; *LF*, gill folds; *M*, Intestine; *R*, Rectum; *MT*, Malpighian tubules; *V*, Tracheal trunk.

The shellfish known as the Mollusca are characteristically marine animals, and by far the majority of animals belonging to this large group are aquatic. It is not surprising

therefore to find that once again the external respiratory organs have the character of gills. The actual organ called the 'gill' is not, however, the only respiratory area, nor is it the most efficient. The layer of tissue lining the shell (the Mantle) acts like a gill (see below). Land Molluscs like the snail have developed a different method of respiration, and since this is also met with in some pond snails, it supports the view that the pond snails have originated from land species which have thus returned again to an aquatic medium.

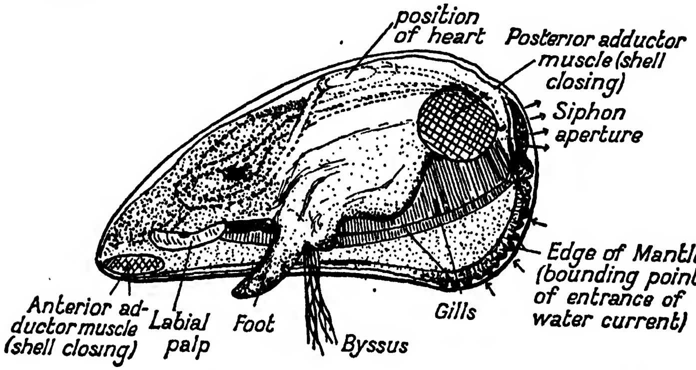


FIG. 57.—Diagram of anatomy of mussel. (Shell, mantle and gills removed from one side. Dotted lines indicate deep-seated alimentary canal only dissected out with difficulty.)

Respiration in molluscs

One of the best known molluscs, easily obtained alive in the large inland towns of England and Wales, is the common mussel. A few specimens placed in an artificial sea-water (see end of chapter) will enable the reader to investigate the action of the respiratory organs. When the animal is in water and the shell valves are opened, the soft tissue lining them (the **mantle**—see Fig. 57) will be observed to project slightly. The mantle edge bears little tentacles. It will be noticed that this extrusion is more prominent at the broad and rounded end of the shell, and two orifices are more or less clearly marked by the approximation of the two mantle edges. If a little powdered carmine or indian ink is allowed to fall very carefully close up to the shell opening, it will be seen that a steady current of water is entering at one point—the **Inhalant**

Aperture—and a current is leaving it at the **Exhalant Siphon** (see Fig. 57). This water not only brings oxygen, but also brings the food supplies.

The blood of the mussel is brought into relation with the sea-water taken into the shell, not only in the gills, but in the mantle, which we have already seen lines the shell; both are respiratory organs. There is one true gill on each side of the body, but it consists of two double sheets of delicate filaments in which the blood circulates.

An interesting feature of the bivalve mollusc is the mechanism for changing the water in the shell. No obvious apparatus is to be seen, but the examination of a small piece of living gill under the microscope soon indicates the cause of the steady current. The gills are covered with strong cilia, and it is by their lashing that a movement of the water over the gills takes place, entering at one point and leaving at another. The gills are more truly food-catching organs, for they not only set up a current of water which is both necessary for respiration and feeding, but they help to direct the food particles to the mouth.

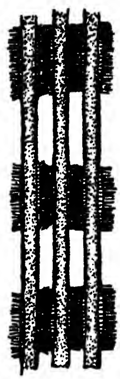


Fig. 58.—View of part of a gill lamella of the mussel, showing three filaments and their ciliary junctions. (After Field.)

When the shell is closed respiration is, of course, reduced to a minimum. The mussel is, however, to a certain extent adapted to this, for it is found between tidemarks and is often exposed for some time between tides. It is able to remain alive for very long periods out of the water. This is not true of all bivalves, some of which perish in a few hours when removed from the water.

Respiration in snail

Breathing in the snail is altogether different. As in the bivalve the layer of tissue lining the shell is known as the **Mantle.** This mantle encloses a little cavity, thus forming a chamber which acts practically as a lung. It is only open to the exterior by a small hole (see Fig. 59), and the mantle forming its roof is richly provided with a network of blood vessels which lie just below the epidermis (see Fig. 243).

Continuous supplies of fresh air are kept up by successive contractions and expansions of the **Pulmonary Cavity.** The snail is so adapted to breathing air—to obtaining oxygen from air—that it is suffocated by prolonged immersion in water. Certain common pond snails which have the same kind of respiratory apparatus have to come up to the surface for air at intervals.

It will suffice to mention briefly a few of our other common types. The earthworm has no *special* organs where the blood is brought into close contact with the air, for this takes place in the skin (see Fig. 64). The body wall is sufficient therefore as respiratory organ, and so long as it is in a moist condition oxygen and carbon di-oxide are able

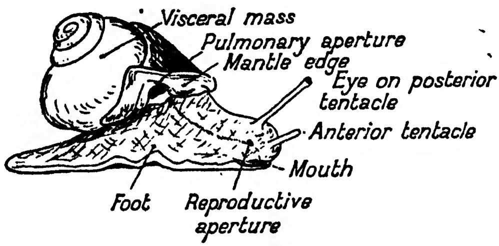


FIG. 59.—Snail from right side after removal of shell.

to diffuse through it from the air to the blood and vice versa. In other worms related to the earthworms and found in fresh water or the sea special organs are developed, and we meet with gills again. This is true of the common lugworm of the seashore.

In *Hydra* all the cells of the body are practically in touch with the external medium (the water), and thus special arrangements for respiration are quite unnecessary.

Practical work on respiration (*see also previous pages*)

I. Observe a living frog under glass bell-jar and note the respiratory movements of throat and flanks as described in preceding pages.

II. Examine the edges of the mouth of a preserved or killed frog and note the exact fitting together of the jaws when mouth is closed.

III. In the springtime collect frog's eggs or tadpoles

(see page 375), and note the gill breathing stages. Examine under microscope.

IV. Observe the respiratory movements of the mouth and branchiostegal membrane of living goldfish in glass aquarium jar.

V. *Demonstration of Carbon di-oxide in the breath.*

(1) Preliminary test. Allow Carbon di-oxide (generated by action of Hydrochloric acid on marble) to bubble into a solution of lime water and note the milkiness produced—deposit of Calcium Carbonate.

$$Ca(HO)_2 + CO_2 = CaCO_3 + H_2O.$$

(2) Fix up two Erlenmeyer flasks as in the figure 61 and place a small quantity of lime water in each (equal

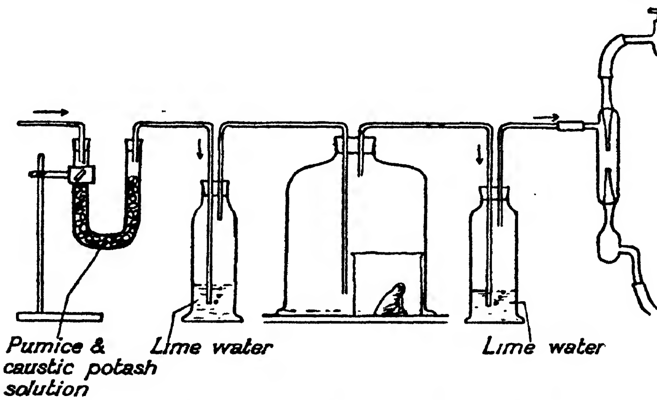


FIG. 60.—Diagram of apparatus for demonstrating respiration.

quantities in each), taking care to cover the bottom end of the long glass tubes. Now breathe gently and slowly through the tube *A*, sucking in air this way and also breathing it out. The fluid in the flasks causes the air to enter by (2) and to make its exit by (1). Note that the contents of each flask go milky, but that flask (1) becomes much more milky than (2). The CO_2 in the air is responsible for the change in (2); that the breath contains much CO_2 is shown by (1). It is easy to add a **U** tube to absorb the CO_2 in the air, and the flask (2) then serves to test the CO_2—free air and flask (1) remains as before the test for the respired air.

Practical work on respiration (*cont.*)

VI. Set up the apparatus illustrated (Fig. 60), which is generally used to demonstrate breathing in plants. Pass a stream of air through, and note the effect when a frog is kept in the bell-jar or a few earthworms are placed in a moist dish within it.

VII. Respiration in mammal and artificial respiration for restoration of the apparently drowned.

The action of the ribs in enlargement of the chest cavity should be watched on a fellow student. Note also the effect of movements of the diaphragm on the abdomen. The methods adopted for the restoration of the apparently drowned depend upon the mechanism for filling the lungs, and these methods form an important illustration as well

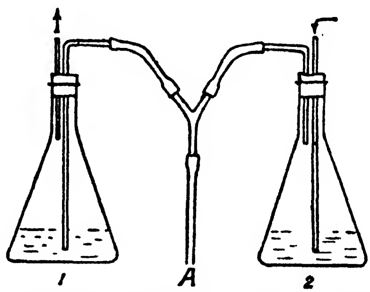


Fig. 61.—Apparatus for demonstration of Carbon di-oxide in breath.

as being useful knowledge. Most persons who have been completely submerged for 4 to 5 minutes never recover. They have been asphyxiated (if not killed by shock). Persons have, however, been restored after fifteen minutes' complete submersion, so that the absence of signs of life should not deter one from commencing artificial respiration and keeping it up for some time. The explanation of the condition of suspended animation is that through lack of oxygen the respiratory control centre in the brain has failed so that breathing is suspended and will not commence again without artificial stimulation. Consciousness has also been lost. The heart, however, being a tough muscular organ, can carry on longer before it fails. The best method for the restoration of respiration is that of Schäfer, and accordingly it is the only one which will be described here.

Schäfer's Method.—In the case of a person who has been submerged in water it is first necessary to clear the air passages and lungs of water. This is done by placing the patient on his stomach with the arms extended and the face turned to one side—the head being on the ground is thus slightly lower than the rest of the body. Kneel astride the left leg of the patient. Place the open hands on the small of the back with the thumbs nearly touching. Then bend forward with arms straight, so that weight of the body falls on the patient. Press firmly downwards for three seconds. Immediately swing back so as to relax pressure (not lifting hands away, however), and let this movement take two seconds. Repeat so that pressure is exerted about twelve times per minute. By this method the air is pressed out of the lungs, and their refilling is dependent upon the elasticity of the chest wall. The tongue should fall naturally into a position allowing free access of air, and the kind of action employed should not only force the air out of the lungs, but any water which has entered. If help is available, others should see to the warmth of the patient by the application of warm dry clothing or by friction.

VIII. The respiratory current in the crayfish may be demonstrated as follows. Have a living specimen in a wide shallow basin of water, deep enough to cover the animal (a white enamel basin will do failing a glass tank, which allows one to see better). With a glass pipette run a little powdered carmine and water mixture below the ventral surface of the thorax between the attachments of the 2nd and 3rd walking legs. Note the appearance of the coloured stream in front of the head. Examine carefully the gills and appendages of a preserved specimen (see page 112).

IX. The respiratory currents of the common mussel may be clearly demonstrated by taking a live mussel (bought at fishmongers) and placing it in sea-water or an artificial sea-water (see page 477). The animal may take a few hours to adapt itself. Use two or three specimens. Use pipette and carmine powder in water as for crayfish.

X. Observe living specimens of mosquito larvae. Note methods of rising to surface to obtain air. Place a few

specimens in water which has been boiled in glass flask and allowed to cool. Carefully float a little oil on the surface of the water in a tumbler containing some specimens. Note the death of the larvae, whose respiratory siphons fail to function through the layer of oil.

XI. Observe living specimens of Mayfly larvae in glass aquarium and under the microscope or hand lens. Note the movements of the tracheal gills. Try the effect of placing the animals in boiled water which has been allowed to cool. Compare result with that obtained with mosquito larvae; the Mayfly larvae respond first by more rapid movements of the gills, and this failing to give the necessary oxygen the animals soon die.

XII. Examine living specimens of dragonfly larvae in a watch glass. Note the tracheal gills. Bring a little finely powdered carmine in water in the vicinity of the anus, and note the currents of water into and out of the rectum.

THE REGULATION OF RESPIRATION

The examples we have taken are but a few to indicate the diversity of the mechanism designed to achieve the same end—to convey oxygen from a surrounding medium to the living tissues of the animal and to facilitate the passage in the reverse direction of carbon di-oxide. The actual movement of the oxygen and the carbon di-oxide through the respiratory surface is largely a matter of simple diffusion. If a little oxygen is allowed to escape from a cylinder of the gas, it gradually diffuses through the room from the point of high pressure until it is evenly distributed. The pressure of the oxygen in the blood of a respiratory organ is normally less than it is in the surrounding air or water, because the blood has come from the tissues where oxygen has been used. Consequently the oxygen diffuses from the outside inwards. In the same way carbon di-oxide diffuses outwards, because it is at a higher pressure in the blood which has come from the tissues than it is (or should be) in the air or water outside. But whilst oxygen

diffuses through the respiratory membranes because of the difference between the oxygen pressure on the two sides, this is not all. The degree of oxidation taking place in an animal and the rate of respiratory exchange are most beautifully regulated. For most animals which have been accurately investigated small variation from the normal in the concentration of oxygen in the air (or the water in the case of an aquatic animal) does not result in an increase or decrease in the amount of oxygen consumed.

Thus goldfish will consume the same amount of oxygen per hour in well-aerated water, as in water which contains quite an appreciable amount less. It is only when this diminution is exceeded and a very real deficiency results that oxygen starvation follows. Similarly with man, the amount of oxygen in the air may be increased very greatly without increasing the rate of absorption into the body. This of course is very different from the combustion of coal in a fire which depends very closely upon the rate of air supply.

If the rate of oxidation taking place in the human body is increased, and this of course takes place if the muscular activity is increased, there is a regulated increase in the respiratory exchange. The rate of breathing is increased and it becomes deeper.

Thus in ordinary everyday life, whilst the oxygen supply in the air may remain constant, the rate of respiration is constantly (and unconsciously) regulated to the requirements of the body. In man, under normal conditions, one of the factors in this regulation of breathing is the percentage of carbon di-oxide in the air of the tiny alveoli of the lungs, which in its turn occasions a certain definite condition in the blood. The normal percentage of CO_2 in the alveoli is $5\frac{1}{2}\%$. If this percentage be increased owing to an increase in the amount of carbon di-oxide given off by the blood (as a result of increased exertion on the part of the body), the rate of breathing increases, so that the air in the alveoli is changed more rapidly.

Naturally if there is an increase in the amount of the carbon di-oxide in the air about us—that is, in the air we

breathe—it should have the same effect. Experiments have shown that this is the case, and the matter is of great practical importance in questions of ventilation. We may quote the following from J. S. Haldane, who has made very careful studies of the regulation of breathing:—"In the air of ordinary rooms carbon di-oxide is formed and oxygen used up by respiration and by the burning of illuminants. The natural ventilation of an ordinary room is, however, so considerable that it is very seldom that the percentage of CO_2 in the air exceeds 0·5%. What effects will the gaseous impurity in such air have? Clearly none that are appreciable. The breathing will be very slightly deeper, so as to keep the alveolar CO_2 percentage constant. . . . The slightly increased breathing will also keep the oxygen percentage in the alveolar air from falling, so that the diminished oxygen percentage in the air will be of no account." We must thus seek elsewhere than in the amount of carbon di-oxide given off for the causes of discomfort in crowded rooms.

VII

THE TRANSPORTATION SYSTEM—THE BLOOD AND ITS CIRCULATION

We have seen that the Protozoan cells are directly in touch with the medium from which they obtain their food and oxygen, and into which they pour out their waste products. This applies also to a few of the lower multicellular organisms, of which *Hydra* is a good example. In the case of *Hydra* the water in which the animal is living not only bathes the cells of the outer layer, but is equally in contact with the cells of the inner layer, because the cavity of the animal is open to the water by way of the mouth (see Fig. 38). Thus each individual cell is practically in the same position as a single celled organism. But in most multicellular animals the majority of the cells are out of direct touch with the surrounding medium, and definite organs are present for the absorption of food, for respiration and for excretion. It is obvious that there must be some transportation system to distribute the products of these different organs.

In some of the lower animals the fluids filling the spaces between the different organs perform this work, and there is no defined circulation in vessels. In the higher forms, however, the transportation system consists of a highly developed series of tubes containing a fluid of rather definite composition called the **Blood,** and to keep this moving along an exact course, a powerful pumping organ is present, known as the **Heart.** In the vertebrates the circulatory system consists of one or two large vessels or arteries which issue from the heart, and by repeated branching result in exceedingly slender and delicately walled vessels termed **Capillaries.** These unite again with each other to form larger vessels known as **Veins,** through which

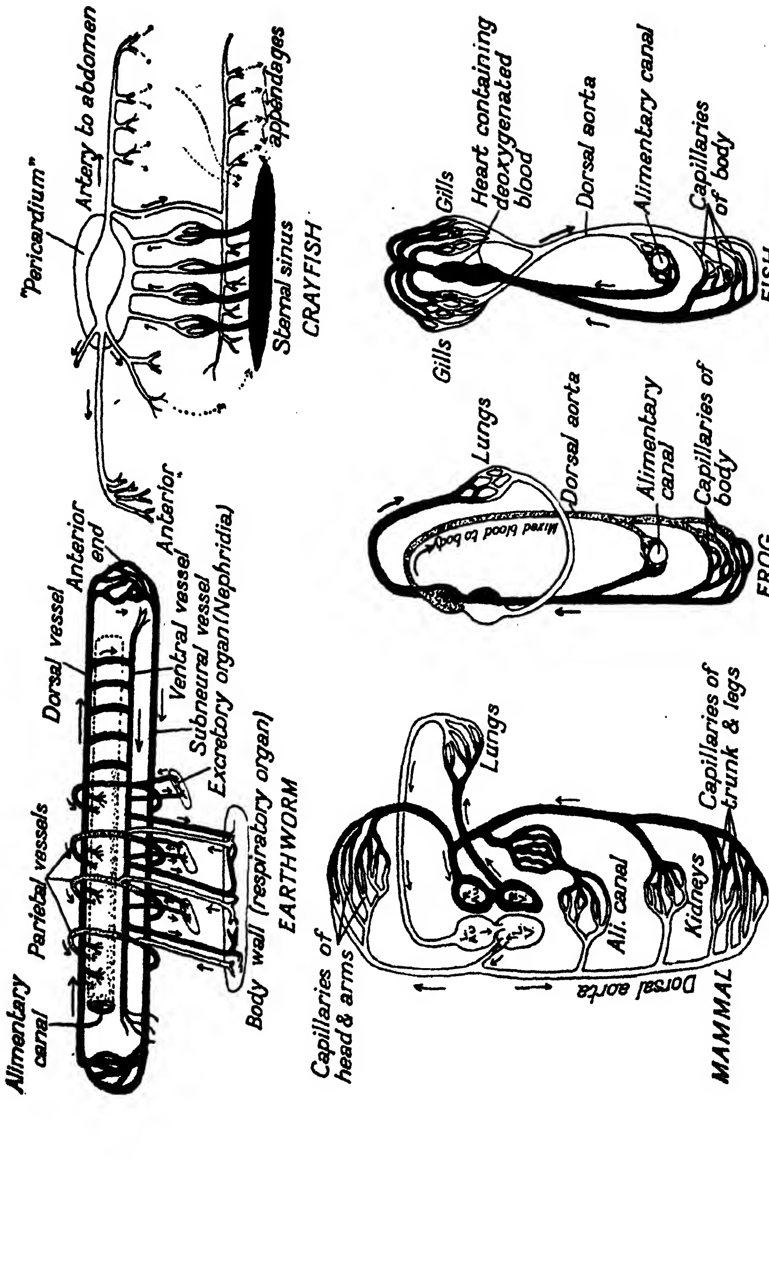


FIG. 62.—Diagrams of blood systems.

the blood always passes back towards the heart. The smaller veins unite to form one or two large veins which enter the heart (see Fig. 62). It will be seen that the blood circulation takes place in a complete and closed system. An intermediate condition is found in some of the invertebrate animals like the Crustacea (crayfish, etc.) and the Mollusca (mussel, oyster, etc.).

It will be simplest to consider a series of examples in order of complexity.

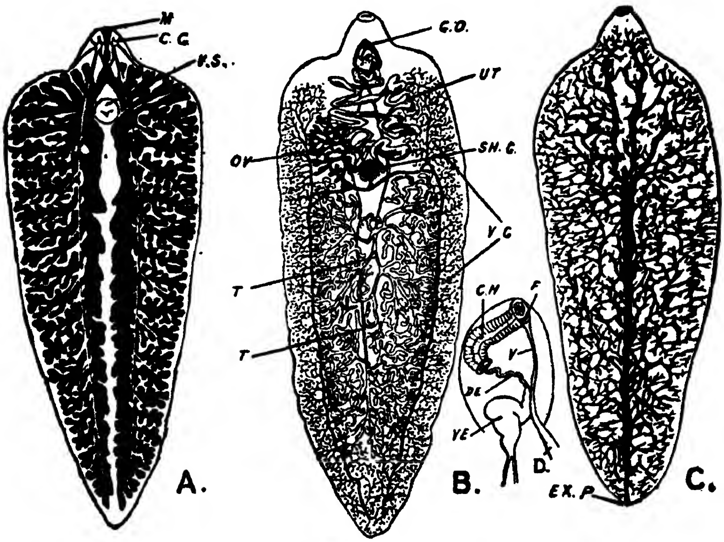


FIG. 63.—*Distomum*. (From Bourne.)
A. Digestive system shown in black. *M*, Mouth; *V.S.*, Ventral Sucker.
B. Reproductive System. *G.O.*, Genital opening; *O.V.*, Ovary; *SH.G.*, Shell gland; *T.*, Testis; *UT.*, Uterus; *V.G.*, Vitelline Glands.
C. Excretory System. *Ex.P.*, Excretory pore.

In some flat worms, of which the liver fluke (a parasite in the liver of sheep) is an example (Fig. 63), the digestive system branches to such an extent over the body that food reaches all parts. Where no definite digestive system is present, as in the tapeworm, the food absorbed soaks through the tissues. The excretory system is also rather scattered, and thus it is possible by diffusion for all cells to obtain food and to get rid of waste. No blood system is present and none is needed.

In the earthworm a well-developed blood system occurs.

Earthworm The distribution of the vessels is shown in the Figs. 62 and 64. There is no single heart, but the blood is kept to a definite course by certain of the vessels having contractile walls, and thus by a kind of peristaltic movement the blood is pushed onwards. Absorption of food stuffs and exchange of oxygen and carbon di-oxide take place in suitable regions where the blood vessels are fine and the walls become thin—that is, in the delicate capillaries—and so one finds special networks of capillaries developed, such as those of the skin, the alimentary canal walls and the excretory organs, in addition to the general network found over the body.

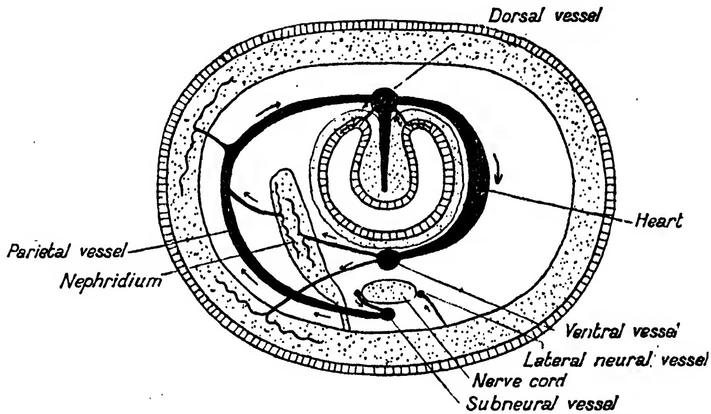


FIG. 64.—Diagram of blood circulation in transverse section of an earthworm. (Modified after Woodger.)

Daphnia In *Daphnia*, and also in other minute crustacea, there are no blood vessels at all. There is a circulating fluid (blood) in spaces, and this is simply kept in motion by the movements of the muscles, etc., of the body, as well as by a small heart (see Fig. 28), which can be seen beating in the living specimens. No vessels enter or leave the heart, and it does not even seem to have a nerve control (see experiments below).

Crayfish In the higher Crustacea like the crayfish there is a very definite blood system connected with the heart. However, this system only partly consists of tubes, for the blood vessels open into large spaces between the organs instead of forming networks of capillaries. The circulation is on the

whole very definite, particularly in regard to the movement of blood to and through the gills for respiratory purposes. As will be seen from the figure, the heart is only a single chamber lying surrounded by the blood. Three pairs of valved openings admit the blood, which enters just as water enters a squeezed and relaxed ball syringe held under water. When the heart contracts the blood is forced out and goes by way of branching **arteries** to all parts of the body. The finer arterial branches open into spaces (**sinuses**) surrounding the organs through which the blood flows until it collects (laden with carbon di-oxide) in a great ventral sinus

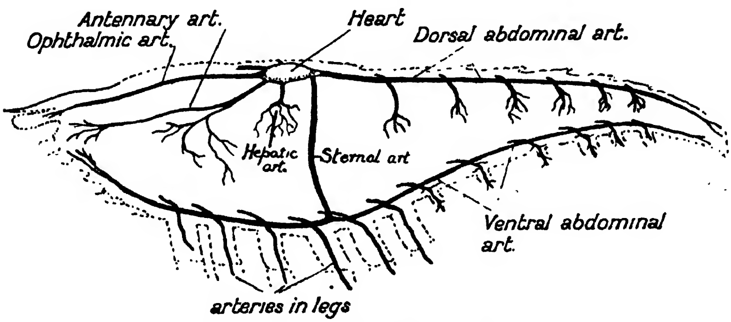


FIG. 65.—Diagram of arteries of crayfish.

(**sternal sinus**), from whence afferent branchial sinuses convey it to the gills to be oxygenated (see Fig. 62, and Chapter VI. Respiration). The oxygenated or arterial blood[1] returns from the gills to the heart, and so the circle is complete. The course followed is therefore: Heart→Body tissues→Gills→Heart.

Insects The Insects are highly specialised animals, and one finds a surprising reduction in the blood system, which is no doubt correlated with the very peculiar and efficient respiratory system of tracheae which results in oxygen reaching all parts of the body in a direct manner (see

[1] It is very general to speak of blood which has become oxygenated in a respiratory organ as pure blood, whilst blood with a high percentage of carbon di-oxide, venous blood, is called impure blood. It is not advisable to use these terms at all. Pureness and impureness imply much that is not characteristic of blood in the oxygenated or deoxygenated state.

Respiratory System, Insect). An elongated heart of many chambers is present, and the blood enters through lateral openings (by suction after contraction) and moves forward from chamber to chamber. In most cases the heart is continued forwards by an artery, the **Aorta** (see Fig. 66), but this soon divides and there are rarely any other vessels. The blood enters spaces between the various organs and tissues and fills the body cavity. The heart serves mainly to keep the fluids in motion.

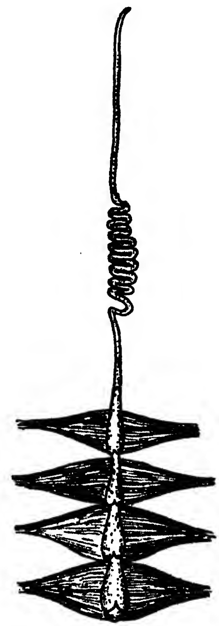


FIG. 66.—Heart and aorta of honey bee. (After Pissarew.)

Fishes In the Vertebrata the circulatory system reaches its highest development, and each group shows an advance which culminates in the birds and mammals. In the fishes there are four chambers to the heart (see Fig. 62), and the blood is received from the veins by one of these, the thin-walled **Sinus Venosus,** passed on to the next, the **Auricle** (perhaps better known as the Atrium in fishes), from there to the very thick-walled **Ventricle,** which forces it out through a tubular chamber, the **Conus Arteriosus.** This last chamber is continued as a vessel with lateral branches to the gills, and so evidently the heart contains deoxygenated blood loaded with carbon di-oxide, all of which is forced to the gills for oxygenation. Vessels convey the blood from the gills into a main trunk, the dorsal aorta, which passes it on by arteries to all parts of the body until the capillaries are reached which make connection with the veins.

The circulation is briefly: Heart→Gills→Body→Heart. The blood is restrained in a closed system, and exchanges with tissues only take place through the capillary walls. In this path the blood gives up waste in the kidneys, takes up food stuffs from the alimentary canal and is treated chemically in the liver (see page 66). The heart must

raise sufficient pressure to force the blood through all these organs, for there is only a single circuit, that is, the blood does not return to the heart until the full course round the body is made. The detailed circuit can be traced from the illustration (Fig. 62). Valves prevent the blood from passing backwards after contraction of the heart chambers (see below). They are situated at the opening of the sinus into the atrium, and at the opening of the atrium into the ventricle. In addition there are valves in the conus arteriosus.

The condition of the circulation in the Amphibia represents an advance on the fish-type. The blood, after being oxygenated in the lungs, returns to the heart before being sent through the body generally. It would almost appear as if it were difficult for the heart to force the blood through the capillaries of the lungs and then on again through the other capillary systems of the body. Whether this is so or not one finds here the beginning of that double circuit which is so characteristic of the higher vertebrates. But this complete double circuit is not perfectly achieved in the frog, and some admixture of blood takes place in the heart.

The action of the heart is interesting. Five chambers are to be noticed: (*a*) the thin-walled sinus venosus lying on the dorsal surface of the heart; (*b*) the right and left auricles; (*c*) the conspicuous ventricle; and (*d*) the tubular truncus arteriosus which leaves the ventricle on the right side. Blood enters the heart by way of the sinus venosus and by the left auricle. The sinus venosus receives more or less deoxygenated blood from all parts of the body, the left auricle receives the oxygenated blood from the lungs. The sinus venosus pours its blood into the right auricle, and so the two auricles receive blood of different quality from two different sources.

Both auricles contract together and drive their blood into the ventricle. It might be thought that this would mean the complete admixture of the two qualities of blood, but a very interesting series of events keeps the two circuits going with only one ventricle, although, as will be

seen, some admixture of blood takes place. The ventricle cavity is broken up somewhat by muscular projections (it might be said to be like a very coarse sponge), and so the blood which has entered it from the right auricle remains at the right side and that from the left auricle remains at the left side, and the two qualities of blood only mix slightly and slowly where they meet in the middle. If the blood

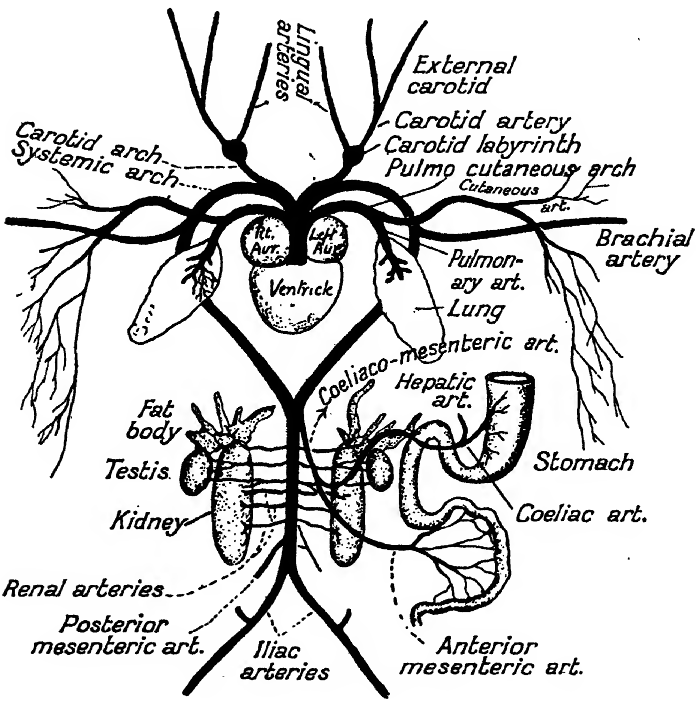


FIG. 67A.—Blood system of the frog. Arterial system.

remained long in the ventricle a complete mixture would of course take place. The ventricle, however, having filled with blood, contracts and drives the blood out through the truncus arteriosus. Naturally the first blood to leave is the deoxygenated blood, which happened to be at the right side and *thus nearest the opening of the truncus.* Now the first part of the truncus arteriosus (in reality the conus arteriosus) contains a spiral valve which divides it longitudinally. The upper part is divided into two chambers,

one communicating with the carotid and systemic arteries (see Fig. 69) and the other only with the two pulmocutaneous arteries.

When the deoxygenated blood is forced into the truncus arteriosus, it passes to both sides, but the pressure in the carotid and systemic arteries is higher than it is in the pulmocutaneous arteries, and so the blood takes the latter

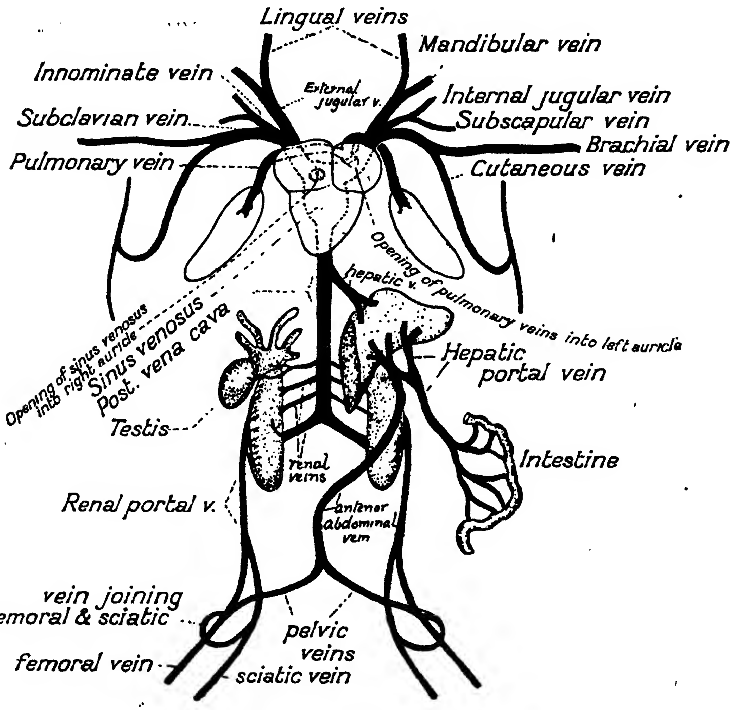


FIG. 67B.—Blood system of the frog. Venous system.

and easier path and goes to the lungs. By the time the contracting ventricle is forcing the last blood out, which is of course the oxygenated blood from the left side, the pressure in the pulmocutaneous arteries has risen so that it is now higher than that in the other main arterial trunks. The result is that the blood now takes the carotid and systemic paths and goes to the head and body generally; and this is aided by the valve in the truncus arteriosus, which is brought into such a position that it shuts off the

pulmocutaneous chamber of the truncus so that the blood can not pass that way.

By these remarkable devices two sorts of blood are driven out of the ventricle by the same path and yet kept separate, so that deoxygenated blood from the right auricle is sent to the lungs where it ought to go, whilst the body, and in particular the head and brain, gets the oxygenated blood from the left auricle.

It should be noted, of course, that the contractions of the sinus venosus, auricles and ventricle follow each other, and that the blood is prevented from going backwards by

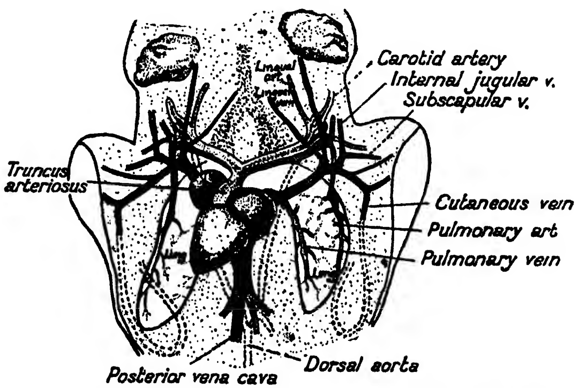


FIG. 68.—Heart of frog and main vessels. (After Röseler and Lamprecht.)

valves which guard the openings from one chamber to another (see Fig. 69).

Mammalia In the Mammalia there is a complete and more efficient double circulation between the heart and the body, one circuit from the heart to the lungs and back, the other from the heart to the system generally and back. The heart is a four-chambered organ. Two of the chambers (the sinus venosus and the conus arteriosus) present in the lower vertebrates (fish and frog) have disappeared, but there are two ventricles in the place of the single ventricle of the frog. (A remnant of the sinus venosus exists in the right auricle, and the conus arteriosus is part of the right ventricle.) There are two auricles. The left auricle receives oxygenated blood from the lungs by means of the pulmonary veins and

passes it on to the left ventricle, which pumps it out by way of the large aortic arch to the body generally. The right auricle receives deoxygenated blood from the system and passes it to the right ventricle, which pumps it by way of the pulmonary arteries to the lungs. The two circuits are therefore distinct, the chambers of the right side of the heart contain deoxygenated blood, whilst the oxygenated blood fills those of the left side. The valves which prevent the backward flow from ventricle to auricle, etc., are described below in connection with the heart of the sheep. The diagram of the blood vessels of the rabbit

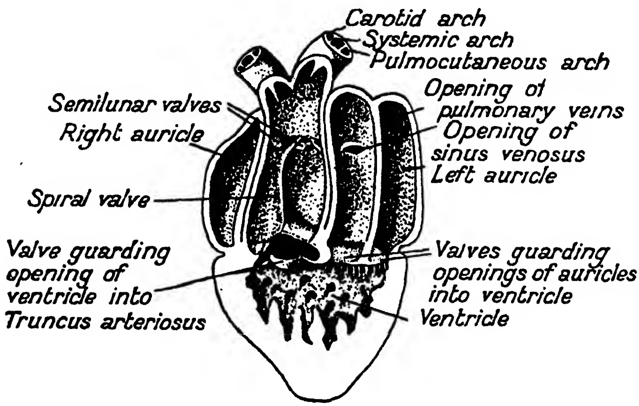


FIG. 69.—Ventral view of heart of frog opened to show internal structure. (After Borradaile.)

indicates the main vessels and the general circulation in a mammal.

Regulation of blood circulation

The circulation of the blood in the body is not quite so simple as we have just depicted it. The heart beat, like other muscle movements, is under the control of the nervous system and it responds, as far as it is able, to the varying demands made upon it. When the muscles of the body are in action a far greater amount of oxygen and fuel substance is needed than when the body is at rest. The heart must pump at a greater speed. This of course in itself involves a remarkable control and some mechanism whereby the needs of the muscles are communicated to the heart. The matter is complicated still further, however, by the

fact that all organs are not always working at the same high pressure, and thus the blood supply must in some way be regulated to the different parts. This is accomplished by contracting the lumen of the blood vessels where blood is not required. In the walls of the arteries there is a layer of circular muscle fibres. Their constriction prevents the abundant passage of blood through these vessels. The

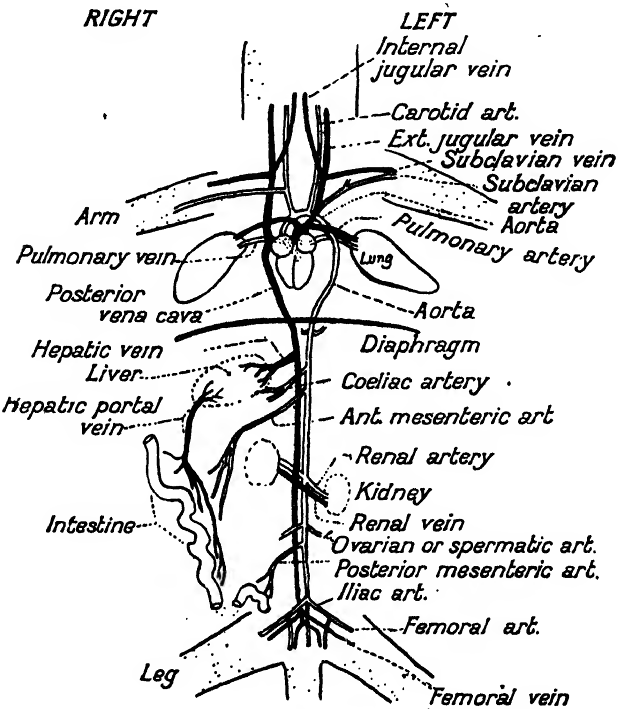


FIG. 70.—Diagram of blood system of rabbit.

control of these muscles is involuntary. In fact, we ourselves cannot prevent it sometimes when it is obvious and not desired. For instance, blushing is due to a relaxation of these muscles in the arteries of the skin. The change of colour to white when the skin is cooled is due to the constriction of the skin arteries in order to prevent the circulation of large quantities of blood in the cold region. The contraction of the blood-vessel muscles is, of course, controlled by nerve fibres. It is also aided by a

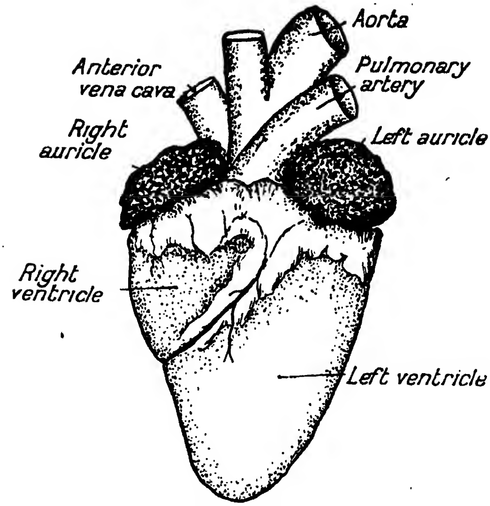


FIG 71A.—Heart of sheep from ventral surface.

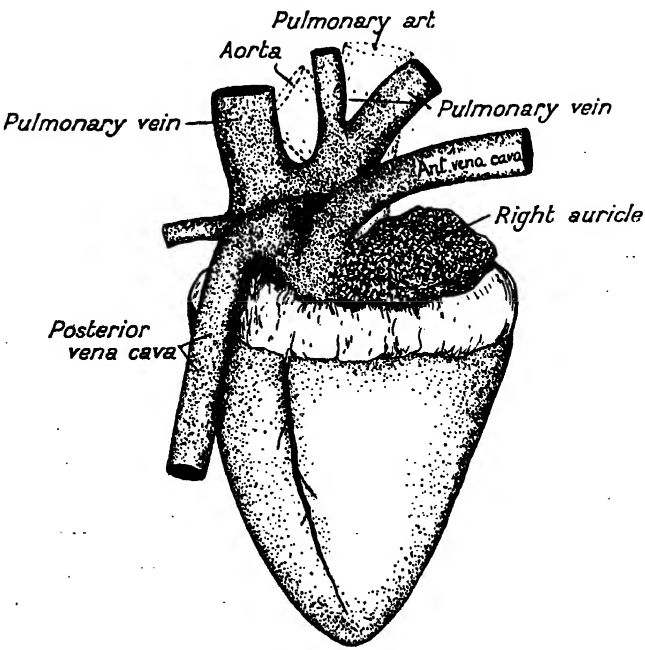


FIG. 71B.—Heart of sheep from dorsal surface.

substance called Adrenalin, which is produced by the adrenal gland.

Practical work on blood circulation

I. *Examine a sheep's heart.*—Notice that the musculature is common to both sides of the heart, that is, surrounds the two auricles and the two ventricles as if each pair were a single chamber. When the heart is pulsating the beat begins by the simultaneous contraction of the two ventricles, after which there is a pause during which the auricles again fill with blood. Note the main vessels entering and leaving the heart (compare with the Figs. 71 and 72), and in particular note the coronary artery which supplies blood to the muscles of the heart walls, which need blood just as any other tissue. This artery is not found in the lower vertebrates, where apparently the blood within the heart cavity suffices for the nourishment and oxygen supply of the heart itself.

Cut through the pulmonary artery and the aorta to expose in each vessel the three semicircular valves which prevent the blood from passing back into the ventricles when the heart expands. Make sections to show the interior of the left and right sides of the heart and observe the valves, which are flaps of tissue prevented from folding back into the auricles as a result of the heavy pressure they must sustain by delicate fibres (chordae tendineae) which cross from muscular papillae on the lower part of the ventricle wall. When the ventricle contracts, the edges of these flaps meet and form a hindrance to the blood, so that it cannot pass back again into the auricles. The valve between the left auricle and left ventricle is formed of two such flaps, and is known as the **Bicuspid** or **Mitral** valve. The corresponding valve between the right auricle and the right ventricle is triple, and is known therefore as the **Tricuspid.**

Note the thickness of the wall of the left ventricle compared with that of the right (a feature correlated with the greater extent of the system of arteries supplied by the left ventricle).

II. *Demonstration of action of heart-valves.*[1]—A sheep's

[1] Experiment suggested by Kuhn (see Fig. 73).

heart is required as fresh as possible *and with the roots of the great vessels uncut.* Remove as much of the fat as possible and cut the vessels near the heart. Insert short wide glass tubes into the aorta and the pulmonary artery, and into holes made in the auricles where the veins which entered have been cut away. Tie the glass tubes (which should have the ends slightly lipped to prevent slipping out) in position and suspend the heart by the tube passing into the aorta, as in the illustration. If water be poured into the auricles it rises in the tubes fixed in the aorta and

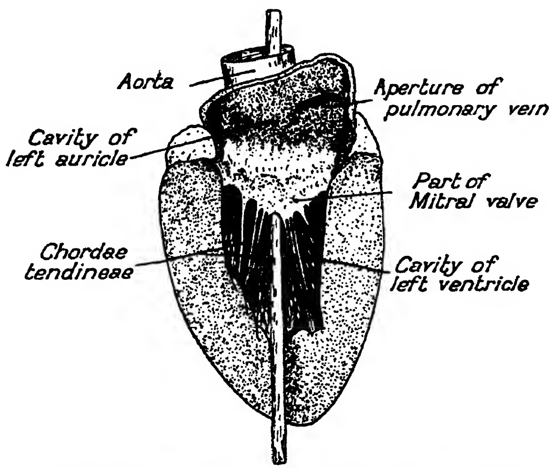


FIG. 72.—Heart of sheep. View of interior of left side of heart with glass rod placed through aorta.

pulmonary artery respectively, and it should still remain at the same height in these tubes if some of the water is removed from the ventricles by means of a narrow pipette pushed through the tubes leading into the auricles. This demonstrates the action of the semicircular valves which allow water to take the course indicated, but prevent its passing backwards into the ventricles. Now, after emptying the heart and pressing it several times, introduce water into the left ventricle by means of a narrow tube through the wide tube fixed in the aorta. The narrow tube must be pushed down below the semicircular valves or the water will not enter the ventricle this way. The left ventricle fills, but as it becomes full the valves guarding the opening

to the left auricle come into play, and the water, being unable to pass further this way, rises in the aorta.

III. Use a simple wooden stethoscope against the chest of a fellow student and listen to the heart sounds. They are often represented by the syllables 'lubb-dup,' the first being longer than the second. The first occurs at the beginning and the other at the end of the ventricular contraction. (The sounds are supposed to be due, at least in part, to the action of the valves.) The number of heart beats per minute depends upon the intimate relationship between the heart action and the intensity of metabolism. In man there are variations with sex, age, muscular exercise and composition of the blood. Thus the average for

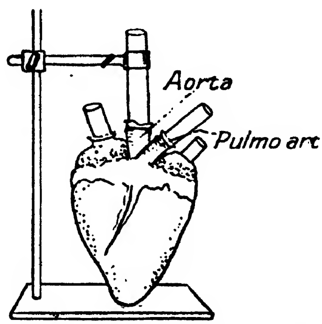


Fig. 73.—Experiment with sheep's heart (see text).

man is 70 beats per minute, woman 78-80, the average at birth is 140, youth 90, adult 75 and old age 70. In the rabbit the rate is 150, and it has been stated that in the mouse it is 700.

IV. Count the number of beats on class mate, and then repeat after the individual examined has been for a short run.

The speed with which blood travels through the vessels in the body depends upon their diameter. The rate of circulation is greatest in the large veins and arteries and slowest in the capillaries, where the best opportunity is thus given for exchange of material with the tissues. The speed can be altered by changes in the strength and rapidity of the heart beat as well as by alterations in the diameter

of the blood vessels. These latter changes are produced by the contraction or relaxation of the muscular wall of the blood vessels and are under nerve control.

The beat of the heart naturally causes the blood vessels themselves to expand as each ventricular contraction takes place. The capillaries, however, completely 'damp' out these irregularities, and so whilst the pulse can be felt quite easily by putting a finger on the arteries, it is not to be felt on the veins. Compared with the arteries the veins are thin-walled and their blood pressure is lower. There are also valves present to prevent a backward flow of blood.

V. Circulation of blood in tadpole tail or frog's foot. Lay a tadpole in a drop of water on slide and keep it from moving by a piece of wet blotting paper over the head, and if necessary over tail end. Examine with low power and note movement of blood corpuscles in the blood vessels. It is possible to distinguish the arterial vessels from the veins by noting the jerky movement of the blood corpuscle current in the former channels. The experiment can be carried out using the thin web between the toes of the frog, but it is not so easy to hold the live frog for microscopic examination unless the frog be covered with a moist cloth bag. The usual method for this demonstration is to kill the frog by pithing it. In this operation the central nervous system of the frog is quickly destroyed by cutting through the spinal cord just behind the head and passing a stout pin or seeker down the spinal cord. Those who have not practised this may prefer to work with a tadpole. Killing a frog with chloroform generally stops the circulation.

VI. If *Tubifex*, a brackish water worm, can be obtained, it should be examined under the low power of the microscope. (*Tubifex* is common in the Thames estuary, and possibly could be obtained through one of the Zoology laboratories of the University of London.) The blood vessels can be easily seen and the flow of the red blood as a result of *peristaltic movements of* the dorsal blood vessel should be noted. Observe also the capillaries of the body wall.

VII. Examine living *Daphnia* under a low power. Note

that the blood has no colour and that blood vessels are absent. Observe the beating of the small heart and count the number of beats per minute. Slightly warm the slide and count the beats again. Within certain limits the number increases with increase of temperature and decrcases with fall of temperature. This is a characteristic feature of 'cold-blooded animals.' (See Chapter IX.)

VIII. Examine living *Chironomus* larvae (see Chapter XVIII) under low power of microscope. The heart may easily be seen beating. Two pairs of openings admit the blood, which is forced along the dorsal vessel above the alimentary canal to the head. Here the blood leaves the vessel and escapes into the cavities, bathing the various organs and tissues.

IX. Stroke the arm downwards towards the hand and note the little swellings rising up in the course of the veins. There is a valve at each of those points which holds up the blood and prevents it passing backward.

X. Take the pulse frequency by applying finger to wrist.

VIII

THE BLOOD

FLUIDS OF THE CIRCULATORY SYSTEM

The observations on *Daphnia* will already have shown that blood is not necessarily red in colour. Its constitution varies in the different animal groups. In all cases, however, the blood is a fluid (the **plasma**) in which float living cells (the **corpuscles**) of one or more types. There are other fluids which fill up spaces between the organs of the animal body. One of the most important of these, in vertebrates, is known as **Lymph.** But this might be said to be part of the blood, for it results through certain constituents of the blood oozing through the walls of the capillaries. After circulating through lymph vessels or lymph spaces, the lymph may be returned to the blood at some definite point. It plays an important part in handing over products from the blood to the living cells and vice versa.

The functions played by the blood are many. It forms the path by which substances may be conveyed from one part of the body to another. The conveyance of oxygen to all living cells and the removal of carbon dioxide is part of the process of Respiration. The blood not only performs this, but carries waste matter of other kinds to places where it may be removed or treated. In addition it is the carrier for food materials, except where these reach all parts in some other way. We now know that it conveys other products from one organ to another, helping to keep the working of all parts of an animal in harmony (*e.g.* the carriage of hormones from the so-called Ductless Glands, the Thyroid, Pituitary, Adrenal, etc., see pages 259*a–d*).

In the more typical cases, the respiratory function of the blood (the carriage of oxygen) is made possible by the

presence of certain substances in it which have a chemical affinity for oxygen. The most usual one is **Haemoglobin,** which is red, and as this is present in vertebrates one always associates blood with the colour red. The haemoglobin may be only present in the corpuscles (and this is the case in vertebrates, some worms and a very few molluscs), or it may be dissolved in the blood fluid, the plasma, as is the case chiefly in invertebrates with red blood—worms, molluscs, some crustacea and some insect larvae (*Chironomus*).

In several invertebrate classes, the blood pigment is not haemoglobin, but a blue copper compound called **Haemocyanin.** This functions in a somewhat similar way to haemoglobin, but the result of its presence is that the blood looks very different indeed (opalescent with bluish tinge) from the deep red vertebrate blood with which we are most familiar. It is found in most crustacea, as, for example, the lobster, crab and crayfish, in most molluscs (snails, bivalves and cuttlefish), and in certain other invertebrates.

There are other respiratory substances found in certain invertebrate animals some of which have no colour at all. They are often altogether missing from insect blood, which does not play so important a part in respiration.

Naturally in the blood fluid one finds various proteins, carbohydrates and salts, and there is some diversity in the kind of corpuscles. It is scarcely possible here to make more than a brief study of vertebrate blood.

Vertebrate blood

The blood plasma is a colourless fluid. When seen in large quantities it is yellow or greenish in man, but water-clear in dog and cat. Floating in the plasma are **Red Corpuscles** (living cells containing haemoglobin), white corpuscles (**Leucocytes**) and **Blood Platelets.** The plasma is 90% water and contains certain proteins, inorganic salts and also the absorbed food stuffs, as well as excretory matter on the way to the kidneys. The most important inorganic salts present, $NaCl$, KCl, $CaCl_2$, $MgCl_2$, are the same ones which cause the saltness of the sea; and it may be noted here that their concentration in the blood of the higher vertebrates is kept remarkably constant. One of the

proteins of the plasma can be obtained easily in the form of fibrin, and it is actually the appearance of this which is responsible for coagulation of the blood (see below).

The red corpuscles are typical nucleated cells of a definite oval flat shape, except in the mammals, where they are circular and *without a nucleus.*[1] They vary in size in different vertebrates, a feature which is graphically illustrated in Fig. 74. The corpuscles also vary in number, as is indicated in the short table given below. The number of corpuscles is that found in a cubic-millimetre of blood :

	Red	White
Dog	6,650,000	10,000
Cat	8,000,000	15,000
Man	♂5,000,000	6,000–8,000
	♀4,500,000	
Pigeon	4,000,000	15,000–30,000
Frog	400,000	5,300
Bony Fish	700,000	
	2,000,000	

It will be noticed that the corpuscles are most numerous in mammals and larger and least numerous in amphibia. The number is also small in the fishes like the dogfish and shark.

Haemoglobin, which is found in the cytoplasm of the cell, is a complex protein substance, containing iron. It can be brought out of the corpuscles by adding water, or by adding ether or chloroform or certain other substances (poison of snake venom, etc.). These substances are known as **Haemolytic Agents,** and the act of discharging the haemoglobin is known as **Haemolysis.**

[Haemoglobin is a compound which may be split up into a simple protein, globin, and the pigment haematin (and other substances in small amounts).]

When haemoglobin is exposed to the air, it unites with the oxygen to form a chemical compound **Oxyhaemoglobin,** but this latter is not a very stable compound, and if placed where oxygen is absent, the haemoglobin separates from the oxygen, that is,

[1] These cells possess nuclei in their young stages.

gives it up. On this property depends its action in respiration. In virtue of the presence of haemoglobin any volume of blood carries about 40 times as much oxygen as it would do if only plasma were present.

The **Leucocytes** or white corpuscles are not only found in the blood, but also in the lymph in spaces amidst tissues, in body fluids, etc. They differ altogether from the red corpuscles, apart from the fact that they lack the red pigment. Their shape is constantly changing, in fact it is amoeboid, and these cells present characters in many ways typical of the unspecialised animal cell. There are several distinct kinds of leucocytes to be recognised according to size, type of nucleus and character of protoplasm

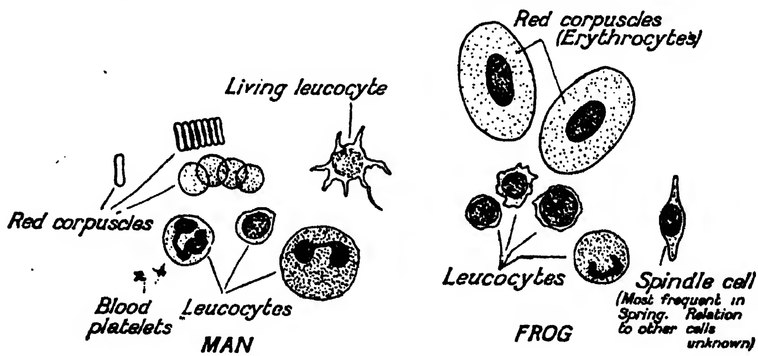


FIG. 74.
A. Some elements of human blood. *B*. Some elements of frog's blood. (Magnification about ×700 in each case.)

(after staining), but this cannot be followed up here. Some of them, like *Amoebae*, can engulf foreign bodies by means of pseudopodia and hence have been called **Phagocytes**.

As we have seen, there are not nearly so many white corpuscles as red ones, and the numbers vary according to place, time and age.

The most striking feature of the leucocytes is their power of wandering—some of them are able to migrate through the walls of the blood capillaries into the surrounding tissues. They may eventually enter definite lymph channels—lymph vessels in the vertebrates—which eventually open into main trunks and lead the excess lymph back to the blood stream proper.

Various functions are attributed to the leucocytes:

(1) They protect the body from bacterial invasion by capturing, or by indirectly destroying, any invading bacteria (Phagocytosis).

(2) They aid in the absorption of food.

(3) They play a part in keeping the constitution of the blood plasma constant.

(4) They play a part, especially in some animals, in *blood coagulation.*

Invertebrate blood

In the snail, the common cockle (*Cardium edule*) and the crayfish, we find that haemoglobin is missing in each case. The blood of the cockle is an opalescent fluid, rather blue by reflected light, and if it is allowed to stand white flocculent masses appear visible to the naked eye. A microscope

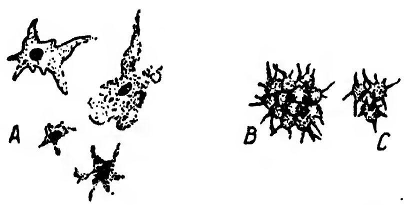


FIG. 75.—Blood corpuscles from blood of mollusc.
In *B* and *C* the corpuscles are agglutinating to form a clot.

will show that these masses are composed of large numbers of leucocytes which have all collected together under the abnormal conditions. The respiratory pigment, haemocyanin, is present in the plasma (in contrast to the haemoglobin present in the red cells in the vertebrate examples). There are no blood corpuscles corresponding to the red cells of the vertebrates, but it is possible to distinguish several types of leucocytes. These leucocytes are amoeboid, and their pseudopodia are rather curious in form. They perform phagocytosis as in vertebrate blood, and they appear to play a big part in preventing the blood from escaping through small wounds in the animal by collecting together (**Agglutinating**), just as they do when the blood is allowed to stand in a beaker (see Coagulation below).

The blood fluid of the crayfish as it oozes from a cut is practically colourless. It appears to be in the reduced

state. Leucocytes are present in it, and three different kinds have been recognised by careful methods, but probably they do not correspond to the leucocytes of mammalian blood. In any case they seem to undergo such rapid changes on exposure to air that there is no point in describing their appearance in detail here, and there is a possibility that all three are only stages in the life of one type of cell. Apparently only one of these types is capable of amoeboid movements whilst in the blood vessels. One type of corpuscle is capable of phagocytosis. Oxygen carriage is aided by the pigment Haemocyanin, which is present in the blood plasma. The blood of the crayfish, like that from the lobster, coagulates quite quickly. A description of this coagulation, which differs from that seen in the vertebrates and also from that of mollusc blood, is given below.

Earthworm The blood in the earthworm is red in colour, but this is actually the colour of the plasma, for the haemoglobin is dissolved in it, and is not contained in corpuscles. The corpuscles are of the leucocyte type—little amoeboid cells.

The above sketches will serve to indicate that whilst the character of blood is more or less uniform in the vertebrates, there is a great variety in the composition and general properties of the blood fluids in invertebrates. On the whole, vertebrate blood is a much more effective medium for oxygenation than invertebrate blood, but the needs of the animals are different and, as we shall see, many invertebrates have great areas in close contact with the outer medium or, as is the case in insects, the air is distributed directly to nearly all the tissues of the body.

(In addition to the functions of the blood that we have mentioned, there is a mechanical one which is independent of chemical composition. The fluid is often used for expanding parts of the body. Thus the foot of bivalve shellfish is extruded by the action of muscles in forcing the blood into it.)

Clotting of vertebrate blood A most characteristic feature of the vertebrate blood is its power of clotting when it escapes from a wound. If a quantity of sheep's blood be taken and left in a large test

tube (stoppered with cotton wool), it will be found that the blood sets to a soft jelly, and that a small quantity of a faint yellow liquid is present. If the tube be allowed to stand, the clot will become smaller and the amount of clear fluid larger. This fluid is known as **Blood Serum.** It is plasma minus fibrin and most of the corpuscles. The clot consists of **Fibrin,** an insoluble protein which is derived from the previously present soluble protein called **Fibrinogen,** and entangled in this mass of fibrin are almost all the *red* blood corpuscles. The fibrin forms as a mass of fine fibres. It is possible to get the fibrin without red blood corpuscles by whipping freshly drawn blood with a bundle of fine twigs or an egg whisk—the fibrin collects upon the twigs and leaves the serum and the blood corpuscles. In this case, the serum looks red like blood (owing to its still holding the red corpuscles), but it will not coagulate. The function of clotting is important, for it prevents great loss of blood by closing the openings of cut or otherwise damaged blood vessels.

The cause of clotting, that is, fibrin development from fibrinogen, must be left for more advanced work. Naturally it would be exceedingly dangerous for the blood to clot within the blood vessels. However, this sometimes takes place. On the other hand individuals are known whose blood when escaping only clots after a long period. Even small cuts may be quite dangerous to these people. (Condition is known as Haemophilia.)

Clotting of blood in cockle and crayfish

The blood of the Cockle will not clot like that of a vertebrate. Probably the peculiar collecting together of the leucocytes (agglutination) which takes place in this form under certain conditions may help to prevent loss of blood in small injuries. Thus a leucocyte ' crowd ' can block up small punctures in the vessels, etc.

In the Crayfish and lobster the process of coagulation is again different, both from that of the vertebrate and from the agglutination of corpuscles seen in the cockle. (*Note.*—The blood of some of the lower crustacea does not clot at all, whilst in other cases the blood cells adhere together and form a kind of clot just as we have described for the

cockle.) A true coagulation of the plasma takes place, although it may be rather slow. Coagulation appears to take place in two stages. The first happening is the formation of a fibrous fibrin-like substance in the plasma. A further stage takes place later and the rest of the fluid becomes a stiff jelly-like mass. Probably the first stage is due to the corpuscles and is not altogether unlike the agglutination of the mollusc blood. The second stage appears to be a coagulation of proteins in the plasma. The coagulation is not so complete as in vertebrate blood.

(1) Examine a drop of blood (from finger) mounted as described on page 463. Note the red blood corpuscles, white corpuscles and plasma. Watch movements of white corpuscles.

Practical work on blood

(2) Examine drop of blood from frog in same way as above, and compare with human blood. Note the different size, shape and structure of the red corpuscles.

(3) Extract a drop of lymph from the dorsal lymph sac of a frog. (The frog should be killed suddenly by 'pithing' and the lymph extracted by means of a fine syringe.) Examine under the microscope. Sketch the leucocytes and watch the protrusion of the pseudopodia.

(4) Make smears of human blood, frog blood and frog lymph according to the methods described on page 463. Stain and make permanent preparations.

(5) Allow about 100 c.c. of sheep's blood (obtain from slaughter house or butcher) to stand in a flask for 24 hours. Note coagulation and the gradual contraction of the clot with the separation of serum. Remove serum carefully for examination. Note that the clot is bright scarlet on surface, but blue black within.

(6) Stir or beat up rapidly a quantity of *fresh* sheep's blood in a jar, with small bunch of twigs or an egg whisk. Another method is to shake violently in a large strong flask containing some glass beads. The fibrin will separate from the serum and blood corpuscles. Pour off the latter and note difference from serum obtained as above (5). Examine under microscope and note that serum contains corpuscles. Remove the fibrin and wash away the blood

corpuscles adhering to it. Preserve it in glycerine for use in digestion experiments.

(7) *Vertebrate blood and relation to oxygen and carbon di-oxide.*

Take a small glass tube containing fibrin-free blood (defibrinated as described above (6)), and add a granule or two of sodium hydrosulphite ($Na_2S_2O_4$). Note the change in colour. The haemoglobin becomes reduced and the blood may be said to be in the venous condition. The experiment may be performed on defibrinated blood diluted with water. Shake up with air and note the restoration of the bright red colour again. In order that shaking up with air should reoxygenate the blood and restore the bright red colour, it is necessary to use the smallest possible amount of sodium hydrosulphite that will bring about reduction.

(8) Add to a sample of absolutely fresh sheep's blood (or ask butcher to add the blood to the following solution) a dilute solution of potassium oxalate. The amount used should be such that the final mixture contains about 0·1% of the oxalate. In other words, if a 10% solution of potassium oxalate is used, one should add a little more than $\frac{1}{10}$ of the volume of the blood taken. Note that this prevents the coagulation of the blood. It has been found that the calcium salts in the blood are absolutely essential to coagulation. Potassium oxalate solution precipitates the calcium salts, and hence clotting is prevented. The blood treated in this way may be made to clot by the addition of a suitable amount of calcium chloride. (*Note.*—Leeches produce a secretion of their salivary glands which prevents the clotting of blood. In this way they are able to procure a large amount from the small incision they make. The action of leech secretion is different from that of the potassium oxalate.)

(9) Make an incision into the foot or the mantle of a living pond mussel (having carefully broken open the shell without damaging the mantle in order to run out the water contained therein). Run the colourless blood into a small crystallising dish and note the gradual formation of little

white flocculent masses. Examine with the microscope and note that they are masses of blood corpuscles which have become agglutinated together.

(10) To a preparation containing a drop or two of frog's blood in normal salt solution under the microscope, add a little concentrated salt solution. Note the shrinkage of the red blood corpuscles. To another preparation, instead of concentrated salt solution, add distilled water. Note the swelling of the blood corpuscles.

(11) To a little sheep's blood (or rabbit's blood) in a test tube add a similar quantity of normal saline solution and then shake with ether. Note that the red blood corpuscles are destroyed and the contents (haemoglobin) enter into the plasma.

(12) (After Jordan.) From a snail which has retracted itself remove a piece of shell near the apex and expose the visceral mass. Clear carefully the surroundings of the opening and pierce the epidermis. Collect the blood in a test tube. By pressing on the animal at the mouth of the shell, the quantity of blood obtained may be increased. Note that the blood is of a blue opalescent colour. It appears to be oxidised.

(13) The haemocyanin can be examined in crustacean blood by making incisions at the base of the legs of a live crab or cutting off the last abdominal tergum of a lobster. The blood should be run into a tube containing some small glass pellets and shaken. The serum may then be poured off from the clot. In the case of crab blood this serum remains fluid. In the case of the lobster a second clotting process follows as noted above and a firm blue jelly results. The serum can easily be obtained by squeezing this jelly through a piece of fine bolting silk. In either case the serum becomes dark blue on shaking with air. The dissociation of oxyhaemocyanin (the oxygenated haemocyanin) is easily observed by placing 5 c.c. of serum in a test tube fitted with rubber cork and single glass tube exit. Exhaust the test tube with a filter pump and shake tube till the serum is reduced (about 5 minutes). Allow air to enter again, shake and note colour change. (Probably quantities

of crustacean serum could be purchased and received by post on application to the Marine Biological Station, Plymouth.)

(14) Examine a little of the blood from a *Chironomus* larva or a large earthworm. Note that the plasma is red, the haemoglobin is present in the plasma.

IX

TEMPERATURE AND ANIMAL LIFE

Animals, whether single-celled or multicellular, are to a large extent adjusted to a somewhat narrow range of temperature. We have already seen in the case of the Protozoa how *Paramecium* will collect under certain temperature conditions. This sensitiveness to differences of temperature is met with in the highest animals, where indeed there are special skin sense organs for its perception. A temperature of 50° C. is death to most living cells, although there are a few remarkable organisms which live in hot springs and are adapted to even 80° C. On the other hand, temperatures below those usually experienced in nature are not so dangerous unless actual freezing of the animal with the formation of ice crystals sets in. But some of the smaller and lower organisms are able to stand very great cold, and bacteria have revived after exposure to temperatures lower than that of liquid air. Thus cold storage may stop the development of micro-organisms, but it does not have the sterilising effect of boiling or heating, and consequently food may very rapidly putrefy after being taken off ice, especially if it were originally heavily infected.

Here, however, we are not concerned so much with exceptional temperature conditions as with the relations of the majority of animals to their normal environments. From this point of view, we shall note that temperature conditions play a great part in the restriction of animal life and its limitation to certain parts of the earth's surface. There are in fact close temperature adjustments between the organisms and their environment. Thus we find that for certain animals the tropics are most favourable, whilst others are only found in colder regions. Some fish live

restricted to the ice-cold waters of the Arctic regions, others are at home in the warm zones of coral reefs. The seasonal variations in temperature are equally important, and if one were to follow the sequence of life in a pond or lake, or the floating life of the English seas, throughout the year, it would be found that the succession of animal life was to a large extent (although not altogether) controlled by temperature changes.

The higher vertebrates present a still more interesting phenomenon, for some of them, like the frog, certain reptiles and even some of the mammals such as the hedgehog and dormouse, go into a kind of sleep when the temperature falls and all living processes are reduced to an absolute minimum. In this condition—**hibernation**—these animals pass through our winter. Other mammals, however, and the birds which remain with us are not so affected. In fact, they may be stimulated to greater activity when exposed to the cold.

"Warm" and "cold-blooded" animals

A little enquiry into these conditions will soon show that animals may be divided into two classes by their relation to the temperature of the environment. With one or two striking exceptions the mammals and the birds have a regulated temperature, which is to a great extent quite independent of the environment. Since these animals are in general warmer than their surroundings (the average temperature of the blood of a bird is 41° C., the average July temperature of the air in England is 18° C.), they have been spoken of as warm-blooded animals. Contrasting markedly with these are the representatives of by far the greatest number of animal groups, for example the reptiles, amphibia, fishes and all the invertebrate classes. They have been called cold-blooded animals, because in general in temperate regions they *do* feel cold to the touch. Both terms, however, are incorrect, and they obscure altogether the essential character of the two groups. As a matter of fact a snake in the hot tropical sun resting on a sandy ground may be quite hot (not necessarily of the same temperature as the ground), yet it is one of the cold-blooded animals in the above classification.

The *real* difference between the two groups is, that in the mammals and birds the temperature of the animal's body is controlled and regulated by the body itself and is remarkably independent of the environment, whilst in the other groups the temperature of the animal is almost entirely controlled by the surroundings, and consequently it rises and falls with changes in the temperature of the environment. More suitable terms for the groups are **Homoiothermic** (= constant temperature) for the so-called warm-blooded animals and **Poikilothermic** (= changeable temperature) for the so-called cold-blooded.

Temperature and chemical reactions in the body

It has been found that within certain limits the speed of chemical reactions conducted in a laboratory is accelerated by 100% to 200% for every rise of 10° C. Now it is not surprising, since the functions of most organs of the body depend upon chemical reactions, that these functions are influenced in a very similar way by changes of temperature. The rate of respiration in goldfish (and this is a good indication of the rate of metabolism) varies quite regularly with variations in temperature. The speed of development of the eggs of most poikilothermic animals is profoundly affected by temperature, and one can stop development, slow it down or hasten it by altering the temperature. Keeping this in mind it is not strange that many poikilothermic animals hibernate during the cold months, for their body temperature falls with that of the environment until it is too low for the metabolism to result in bodily activity, and the animals thus appear to be asleep or even dead.

Under the same environmental conditions the homoiothermic mammals and birds, in general, keep up their temperature, although there are limits to this, and they may find it difficult to do so when the days are coldest. In some mammals, however, the mechanism regulating temperature appears to be insufficient or does not function under certain conditions. These animals are apparently typically homoiothermic during the warmer months of the year, but when the temperature of the environment falls below a certain point, the temperature of the body drops, and they become to all intents and purposes poikilothermic

creatures and then hibernate. The dormouse, hedgehog and squirrel are typical examples of these in our own country. Since this hibernating period is one during which it is difficult for these animals to obtain food, the peculiar conduct of the body must not be looked upon as resulting from a defect. It is probably in the nature of an adaptation.

Some of the poikilothermic animals, notwithstanding the way in which their body temperatures change with the environment (and thus in spite of variations in the rate of their metabolism), are capable of withstanding very great differences in temperature. Such, for example, are some of the inhabitants of shallow rock pools (especially fresh water pools in continental countries), which may be warmed up by the sun in the daytime and cool down considerably at night. Animals which live on the snow of the Alps, Himalayas, etc., are subject to even greater changes of temperature.

Birds and mammals, and temperature regulation

Since evolution amongst the vertebrates has led to groups of animals which show distinct evidences of independence of external conditions, it is natural to find that the highest groups have evolved mechanisms for keeping the body temperature constant notwithstanding environmental changes. We shall examine the mechanism in one or two examples. The temperature of the body in the mammals and birds is dependent upon (1) the relation of the amount of heat produced to the area of the body surface, (2) the condition of the cutaneous blood vessels, (3) the degree of development of non-conducting layers which hinder the passage of heat from the body (hair, feathers, fat layers below the skin) and (4) the action of sweat glands, if present, or other evaporation surface.

The production of heat is dependent upon the constitution of the body, and it is increased or decreased by varying the amount of oxidation taking place—a change which may be achieved by muscular activity or by the food. Everyone knows that muscular exertion is attended by a rise in temperature. In the tropics the European endeavours to leave arduous muscular work alone, and he is inclined to

this by a general feeling of lassitude in very hot weather. In very cold weather it is more comfortable to keep moving. The body itself may involuntarily use this method of heat production ; shivering is such an involuntary muscle movement for the production of heat. (A few poikilothermic animals may raise the temperature of their bodies obviously above that of the environment by very strenuous muscular activity. In most cases, however, the heat energy acquired in this way is not sufficient to be very obvious, especially since its loss is not hindered.)

The effect of food in producing heat is most marked in the case of man when the air temperature is high, as in tropical countries or perhaps during a hot English summer.

Heat is lost from the body : (1) by radiation from the surface, (2) by the air which leaves the lungs and which is nearly saturated with water vapour and (3) by the evaporation of sweat from the skin when sweat glands are present.

The relaxation of the skin blood vessels and the flushing of the skin brings quantities of blood near the surface. This alone would aid in the loss of heat (unless the temperature of the air were higher than that of the body). The surface layer of the skin may, however, be cooled by rapid evaporation, and thus, if the air be dry and the sweat glands actively pouring out sweat, the skin surface becomes a very efficient cooling surface even under conditions of great heat. Thus flushing of the skin with blood and perspiring are regulatory mechanisms for cooling the body.

Bearing this in mind one understands how it is possible for man to withstand 105° F. in the shade in Western Australia or California with less discomfort than 90° F. in the shade in Colombo or even in London. In Colombo the air is usually moist, and consequently the sweat does not evaporate sufficiently quickly to cool the skin. Where the air is very dry higher temperature can be withstood, because of the action of the sweat glands, temperatures indeed which might prove fatal in a moist atmosphere.

When the air is colder than the body and there is a tendency for the body temperature to fall through excessive loss of heat, the sweat glands do not pour out their secretion

to such an extent, and, moreover, the skin blood vessels are constricted so that the blood is not allowed to circulate so much in the cooling surface region of the body. It is this withdrawal of the blood from the surface of the skin which causes us to become 'blue' from cold.

The presence of a layer of fat in the skin also prevents loss of heat to a certain extent, but in most mammals and birds the hair and feathers are most effective in preventing heat loss, because they cause the body to be surrounded by an air jacket. The subcutaneous fat becomes of extreme importance in the case of mammals which live in the sea. Fur would under these conditions be useless as a non-conductor. In the whale the layer of subcutaneous fat has been extraordinarily developed; it is the blubber so much sought after by whalers as a source of oil.

Where a coat of hair or feathers serves to produce a non-conducting layer for the prevention of heat loss, it may interfere altogether with the action of the skin as a cooling organ, that is, with the action of the sweat glands. In the dog, for example, most of the skin is free from sweat glands, and, of course, there are none at all in birds. Reduction of temperature is achieved here by loss of heat *via* the lungs. A panting dog is cooling itself by rapid loss of heat *via* the lungs and mouth. (It does not follow that all animals with fur have no sweat glands. It is easily seen, for example, that they are present in the horse, the sheep, etc., etc.)

In the mammals the constancy of body temperature is remarkable, and in man it is used by the physician as a guide to the condition of health. In man the normal temperature is often taken as being 98·4° F., but as a matter of fact it varies slightly during the 24 hours, and is less between midnight and 8 a.m. than it is during the period 8 a.m. to 12 midnight. The variation, however, is not great. There is little or no difference whatever between the body temperature of Europeans in Europe and in the tropics. To a remarkable extent man depends upon an artificial covering as an assistance in retaining heat within the body. Probably he lost his hairy covering as he learned

to cover himself with skins. It is clear that, despite the regulatory power touched upon above and the faculty the animal body has for adaptation, the temperatures most suited for man average 60–70° F. The hottest parts of the tropics are not most favourable even for the negro, and the coldest parts of the globe inhabited by man are really below the optimum for him.

Hibernating mammals

Let us now consider one or two of the hibernating mammals which function like homoiothermic animals in the summer, but like poikilothermic creatures in the winter. The fact is, that if any so-called warm-blooded animal is subjected to such a cooling that it cannot keep its body temperature up to the normal point, its temperature falls until eventually constancy is lost, and it rises and falls with changes in the environment just like any typical 'cold-blooded' animal. Of course, in most cases this means death to the 'warm-blooded' animal. The hibernating mammals are, however, exceptions. 'Hibernation' is used to denote the peculiar somnolent state in which some warm-blooded and many cold-blooded animals pass the winter. Amongst mammals the best known examples are the bats, hedgehog and dormouse. In the most typical examples of hibernation the animals make no stores and sleep right through the winter. In others, however, food is laid up in the nest, so that the animal may feed if it wakes at intervals during the winter. The former is the case for the hedgehog and the bats, and the latter applies to the dormouse. Squirrels are not altogether true hibernators; they wake up frequently and feed on stored food. On the approach of cold weather, the hedgehog retires to a hole under roots of trees or in rocks, and there in a comfortable little bed it coils up and enters upon its peculiar sleep. The temperature of the body falls until it becomes quite cold to the touch ; all control is lost, so that its temperature varies with that of the surroundings. The force and frequency of the heart beat is greatly reduced, in some cases it can scarcely be detected at all and the blood flows very very slowly. Respiration is similarly slowed down and is very irregular.

During hibernation the dormouse has been found to take from 10–15 inspirations, and then an interval of several minutes passes without one at all. When awake this animal respires at the rate of 80 inspirations per minute.

It is possible to awaken these hibernating animals, and in such cases the temperature of their bodies rises in a remarkable manner, so that in a few hours the animal becomes once more typically warm-blooded. If the animal has been awakened by actually raising the temperature of the surroundings, and consequently the temperature of the animal has risen to a certain extent, its continued rise is still more rapid. This is illustrated by the following example of a dormouse (Pembrey and White's figures). The table shows the relation between the temperature of the hibernating animal and that of the surrounding air.

Time of day.	Temperature of animal.	Temperature of room.
9·10	3·0° C.	2·75° C.
9·35	6·1	10·0
10·00	8·3	10·2
10·30	8·9	10·9
11·00	9·7	11·1
11·30	6·1	2·75
11·50	4·9	2·75
12·30	3·9	2·75

The temperature of the room was raised to 16° C. and the animal then woke up. Ten minutes afterwards its temperature was 36° C.

The normal awakening of hibernating mammals is brought about mainly by the occurrence of warm weather. The exhaustion of stored-up reserves in the body as well as the need of getting rid of waste substances also plays a part.

Hibernation is a peculiar condition associated with the cold season of the year. There is, however, another type of 'sleeping' condition, **Aestivation,** which is associated with summer or rather with hot and dry seasons. It has been little studied, and in some cases it presents great

difficulties. In the case of certain small invertebrates of fresh water the animals undergo a kind of drying up, and in this condition may remain with the power of continued existence when favourable conditions return. The term summer sleep or aestivation is not usually applied to this condition, but rather to that seen in certain fishes, frogs and reptiles (particularly crocodiles and lizards). Thus the West African mudfish (*Protopterus*) curls itself in a little tube-like burrow in the mud of the African rivers, and remains in this state of coma whilst the water dries up. Lumps of dried mud containing mudfish have been brought to England and the animals revived by placing in aquaria. This type of resting period is obviously a response to dryness. There is a tendency, however, in some other cases for prolonged periods of repose on the part of land animals during the hot weather. Little is known of the physiological conditions under these circumstances.

X

THE ANIMAL SKELETON

Even amongst the Protozoa one finds hard or semi-rigid parts developed within or without the animal and serving as supports or protective structures. Living protoplasm being semi-fluid, it is only to be expected that in the larger multi-cellular animals, a skeleton of some sort should become an absolute necessity in order to bear the weight of the body and keep the different organs in their place. However, the production of a skeleton for support or protection or both is complicated by locomotory needs, which are so characteristic of animals. It might be said that there is a conflict between the use of a skeleton for protection and support on the one hand, and the needs of growth and movement on the other.

The term skeleton is used for all semi-rigid or rigid parts of the animal serving for support, protection and attachments for muscles. It may be internal or external, and it ranges from the horny skeleton of the bath sponge and the limy skeleton of the corals to the external case of chitin of the insects and crustacea, the shell of the snail and oyster and the internal skeleton of bones of the higher vertebrates.

Much of the interest in a study of animal skeletons depends upon the innumerable variations associated with the rest of the structure of the animal and with its habits. The thickness or length of a bone has a meaning ; the size and shape of a scar or roughening where a muscle was attached gives a clue to more than the size of a muscle ; from the character of teeth we can deduce the type of food, and so on. Since skeletal parts have been most frequently the only remains of an animal preserved as a fossil, this ability to construct the whole from a few parts is not only

of exciting interest, but of great importance. Its possibility depends on a knowledge of the relations of skeleton and soft parts in living forms.

Certain multicellular animals, like the earthworm and other wormlike animals, are almost without anything which functions as a skeleton. The body form is retained and a certain amount of rigidity developed by the tension of the muscles acting on cavities filled with fluid. By this means the earthworm can burrow in the earth and the anemone

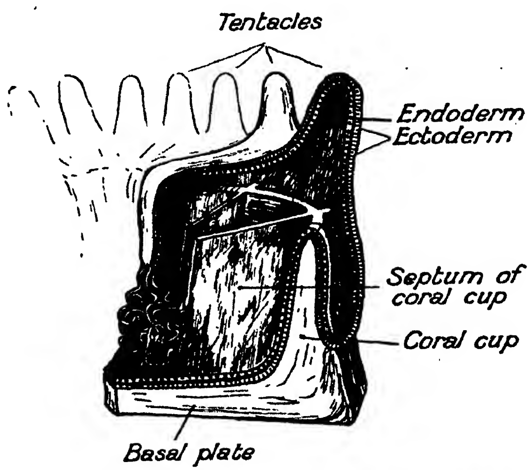


FIG. 76.—Part of a coral polyp (diagrammatic) to show coral skeleton.

can expand and unfold its tentacles. Even the octopus depends largely on this method for retaining its body form.

In *Hydra* and in the anemones and jellyfishes the only supporting structure is a layer of gelatinous substance between the two cell layers of the body. It is called **Mesogloea** (see Fig. 38). In other members of this group of animals the mesogloea is invaded and stiffened by small concretions or **Spicules** of lime which have been secreted by the ectoderm cells. These are so numerous in some cases that they form a solid mass, as, for example, in the precious red coral of the jeweller. The *real* corals, however, possess a skeleton formed by the secretion of lime on the *outside* of the ectoderm. Great masses may be built up by the colonial members of this group, which reproduce so extensively by fission.

It has been stated above that in the ringed worms there is little which can be called a skeleton. However, the body is bounded by a delicate **Cuticle** which is formed by the outermost cells—the ectoderm (see Fig. 113). This layer is interesting, because it is the forerunner of the thick cuticular skeleton of the crayfish, crabs and insects.

There are many examples of animals which protect themselves by building external cases of sand grains, mud, fragments of wood, etc., and there is every conceivable grade between lining a burrow with secretions from the outer

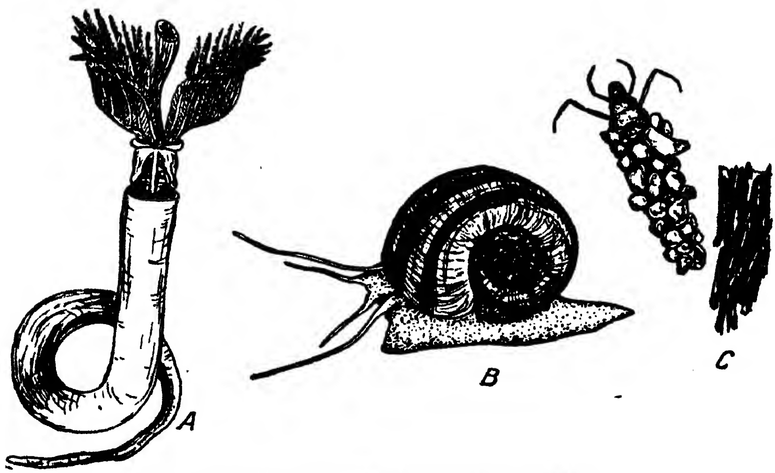


FIG. 77.—Some shells and cases, secreted and otherwise.
A. Marine worm. *B*. Mollusc. *C*. Caddis worms.

surface and hardening these secretions on the outer surface itself so as to form a tube or a shell like those possessed by some of the worms and the Mollusca—the snail, cockle and mussel, etc.

THE SKELETON OF THE ARTHROPODA—THE CRAYFISH, CRAB, INSECTS, ETC.

It is in this phylum and in the vertebrates that skeletal structures are most highly developed. The skeleton of an Arthropod consists of a more or less thick cuticle which is formed from the outermost parts of the epidermal cells. It is partially composed of a nitrogenous substance—**Chitin**

—but this only forms 30–50% of the cuticle which also contains *Cuticulin* of unknown composition. It is perfectly continuous over the whole surface of the body, and thus the limb skeleton might be said to be tubular. In the Crustacea, like crabs, lobsters and crayfish, the cuticular layer is not only thick, but is hardened by deposits of lime. But the Arthropods are active animals, and therefore a rigid outer skeleton is unthinkable. Their skeletons are characteristically jointed, both the body and the legs. This jointing, however, does not break the continuity of the skeletal layer. A joint appears to be the meeting place of two separate rings. Actually it is a place where the cuticle is thin and flexible and is folded (see Fig. 79).

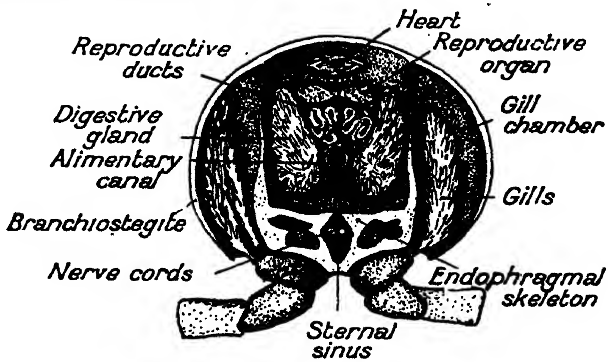


FIG. 78.—Diagram of transverse section through thorax of crayfish.

An imitation Arthropod joint could be made by taking two cylinders of cardboard, one of slightly larger bore than the other, and connecting the two all round with a piece of thin calico pasted on. If the smaller cylinder were then just pushed so that it projected a little into the larger, one would have something like a Crustacean joint. The two cylinders of card could be bent on each other, however, in any direction. This is not usually the case in the Arthropods. Each joint is rather restricted to movement in one direction. This is easily seen by bending the big claw of a crab or crayfish to and fro (see Fig. 79). In order to get movement of the tip of such a limb in all directions, it is necessary therefore to have several joints and for the axis of each joint to lie in a different plane.

The skeleton serves for the attachment of muscles, and one joint is moved on another by this means (see Figs. 80 and 81).

There is great diversity in the manner in which the skeleton is developed in the Arthropoda. In some species, particularly in small forms like *Daphnia* and *Cyclops* (see Fig. 218), it is rather thin all over. In some cases,

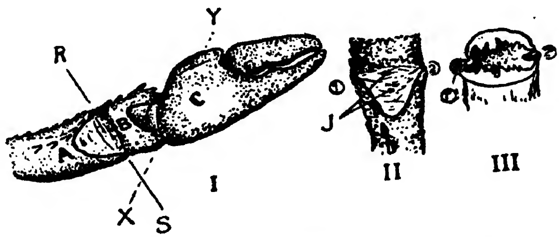


FIG. 79.—Limitation of movement in arthropod joints.

In I. the joints *A* and *B* only move on an axis which passes through *RS*. The joints *B* and *C* rotate on an axis *XY*, which is almost at right angles to the preceding axis *RS*.

Figs. II. and III. show why the joints can only move in one plane. Fig. III. shows appearance when joint is broken through. (1′) and (2′) are the articulating surfaces.

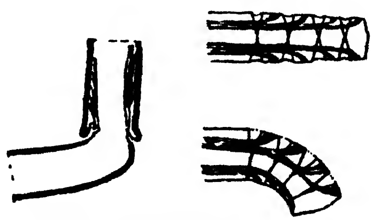


FIG. 80.—Arthropod joints and muscles.

where there is an external protection, it remains thin even in larger forms (as, for example, the abdomen of the hermit crab, which uses a borrowed shell (see Fig. 82), or the abdomen of the water-beetle *Dytiscus*, and other beetles where the thick horny front pair of wings—**elytra**—act as a protection).

In all cases, however, this enclosing type of skeleton has the same grave disadvantage, it is a hindrance to growth. And so we find a remarkable feature in arthropod life, the **Ecdysis** or periodic moult of the skeleton. Shortly before

ecdysis takes place the growing animal separates its epidermis from the shell. An actual increase in the number of cells of the animal will have been taking place gradually, and thus growth is not a matter of sudden jumps, although it seems so. Then a split occurs in the shell (in the crayfish it is a dorsal split along the flexible part joining the first segment of the abdomen to the thorax). This is sufficient for crayfish, lobster and many other types of Arthropods,

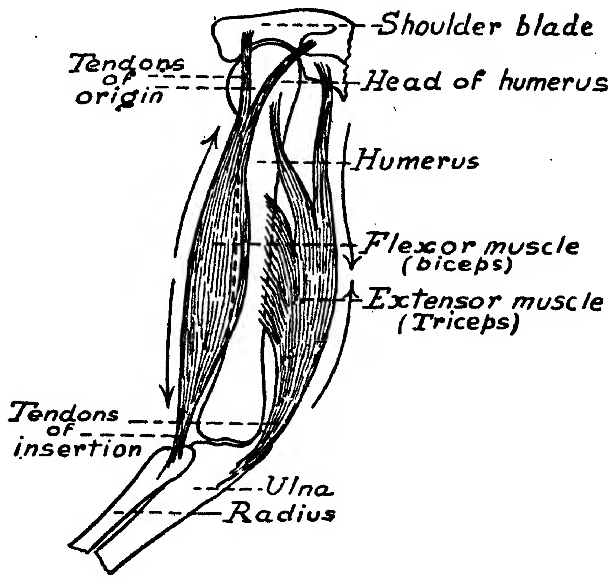


FIG. 81.—Elbow joint of man. (From Johnstone.)

and in a very remarkable manner the animal withdraws itself out of the old shell so carefully that a casual observer, seeing the cast off shell and the animal by its side, might think that two animals were present. In some other Arthropods the cuticle is shed in fragments.

The soft-bodied animal is now free to expand. In a few days the outermost parts of the epidermal cells will once more have hardened, a new cuticle will be developing, and further increase in size is restricted until the next ecdysis. Thus ecdysis is necessarily very frequent during the early life (larvae of insects and the young of the

Crustacea), when growth is most rapid. Fully-developed winged insects no longer perform ecdysis, and in old Crustacea it only takes place at long intervals.

Contrast of invertebrate and vertebrate skeletons

The Vertebrate Skeleton is altogether different from that of the crayfish, insects and their allies. It is essentially internal and is formed of cartilage, which is exceedingly rare in invertebrate animals, and of bone, which is never found at all outside the vertebrate group.

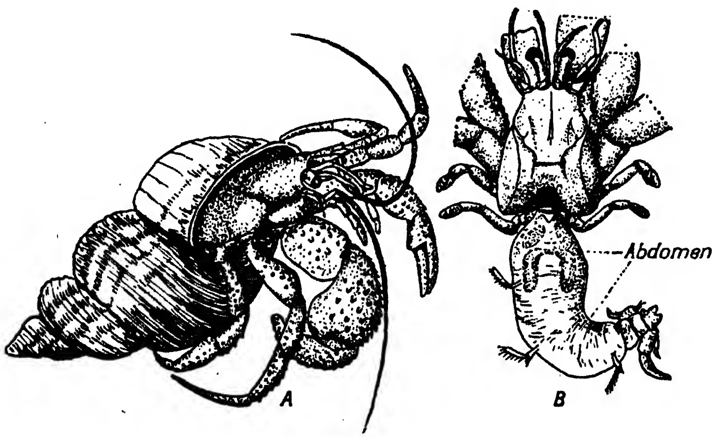


FIG. 82.—Hermit crab.
A. In borrowed whelk shell. *B*. Removed from shell. (After Jackson.)
Note delicate abdomen and reduced nature of appendages covered by whelk shell.

As a protection for the soft parts of the body this type of skeleton is not so effective as the crayfish skeleton, except when it encloses a cavity in which the more delicate parts lie, such as in the protection of the brain, spinal cord and the organs of the trunk.[1] It has not the disadvantages, however, in regard to growth or locomotion.

A 'skin skeleton' or **exoskeleton** is, however, often present in vertebrates as well as the internal or **endoskeleton.**[2] It takes the form of scales, feathers, hair, nails,

[1] There are special cases, as, for example, the tortoise and turtles, where a very efficient bony box is found enclosing the body.

[2] Parts of the endoskeleton may become external, as, for example, the antlers of the deer.

hoofs, horns, etc., and in some cases may form, with the underlying endoskeleton, a very efficient armour (crocodile, for example).

So far as the vertebrate endoskeleton is concerned, it is important to note the fundamental nature of the structural plan. Despite the diversity of form in the different groups (compare a fish, a frog, a bird, bat, rabbit and man), the essentials of the skeleton are the same. There is, of course, a remarkable variation in the development of the different parts; sometimes they are big and strong, some-

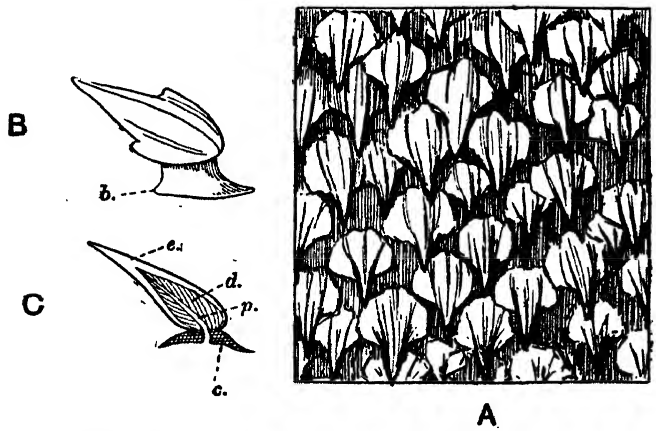


FIG. 83.—Placoid scales of a dogfish. (From Borradaile.)
A. Portion of skin as seen with hand lens. *B*. Single scale.
C. Scale in section: *d*., dentine; *e*., enamel; *p*., pulp cavity.

times small and delicate, sometimes parts are altered, reduced or missing, but the ground-plan is obvious in the most modified examples. This feature is evidence of the common ancestry of the vertebrates; in other words, it suggests that the different sub-divisions have arisen by evolution.

It would be quite beyond the scope of this book to describe the different components of the skeleton of even a limited number of vertebrates. The student should examine for himself the skeleton of a fish, the frog, a bird and a mammal, such as the cat or rabbit, using the illustrations as guides.[1] In the following pages we shall take a number of examples to illustrate points of general interest.

[1] The reader must also understand his own skeleton!

THE VERTEBRATE EXOSKELETON

The well-known scaly covering of fishes consists of small plates developed in the skin. In the dogfish and its relatives (skates and rays) these structures are termed **Placoid Scales.** They consist of a cone of **dentine** capped by a harder substance, **enamel**, and this usually projects through the epidermis. The cone has grown out, and the outer layer of the skin is worn off. These scales are so arranged that projecting edges or points are directed towards the tail, and thus offer the least possible resistance to forward movements of the fish. At the base of the cone a plate of **dentine** develops, and this usually lies buried in the skin. Placoid scales are of interest, because in their structure and development they resemble teeth, and they are really the same sort of structures. (Cf. Figs. 84 and 89.) Often one may see all grades of transition from scales to teeth over the margin of the lip of a fish belonging to this group (sharks and rays). It must not be forgotten, however, that the scales of the bony fishes (Teleostei), such as the herring, mackerel, cod, etc., are different from placoid scales. Each is a flat platelet which develops more deeply in the skin and remains covered by the epidermis. They often present rings which indicate variations in speed of growth, and from these (if other confirming observations have been made) an indication of the age of the fish may often be obtained (see Fig. 85). **Scales of fishes**

The scales of snakes and tortoise-shell are not comparable to the scales of the bony fishes or the placoid scales. They are horny structures developed in the epidermis.

Feathers are characteristic features of the birds, and are developed in no other group of animals. They not only serve to keep the body warm (cf. Chapter IX) (the body temperature of birds is higher than that of mammals), but are utilised to form the wing surface and a tail for steering during flight, besides being often extremely decorative. There are several kinds of feathers, but all are variations of three types. **Filoplumes** (hair-like feathers, often visible on a bird which has been plucked), **down feathers** (plumulae) **Feathers**

and **contour feathers** (plumae). The contour feathers cover the body, neck, head and wings, and are often gorgeously coloured. As the name indicates, they give the general

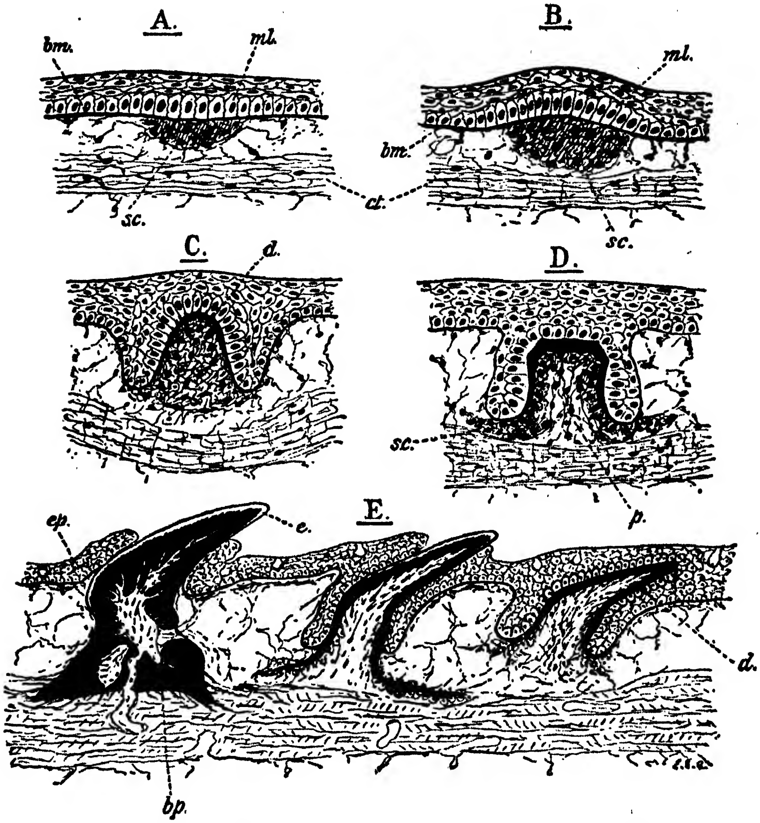


FIG. 84.—Development of placoid scale of dogfish. All the figures represent sections through skin.

A shows the preliminary specialisation of a group of dermis cells. *C* shows how by accumulation these cells have produced a papilla projecting into the epidermis. Dentine (black in drawing) is produced by the outermost dermal cells. The lowest layer of the epidermis produced the enamel (Fig. *E.e*). (After Goodrich.)

outline of the body of the bird. The down feathers occur between them.

Feathers - The feathers are not developed 'anyhow' on the skin, but are arranged in definite tracts. It is often stated that they have been derived from scales like reptile scales, and birds often still possess scaly covering on the legs which is

a derivative from a reptilian ancestor. Both structures arise from the same layer in the skin, but whether feathers have actually arisen from scales is a matter of dispute.

The structure of a quill feather from the wing of a pigeon illustrates the chief characteristics of a contour feather. It consists of a central axis, the base of which is cylindrical and hollow, or nearly so, whilst the rest is solid and somewhat square in section with a groove along one side. The

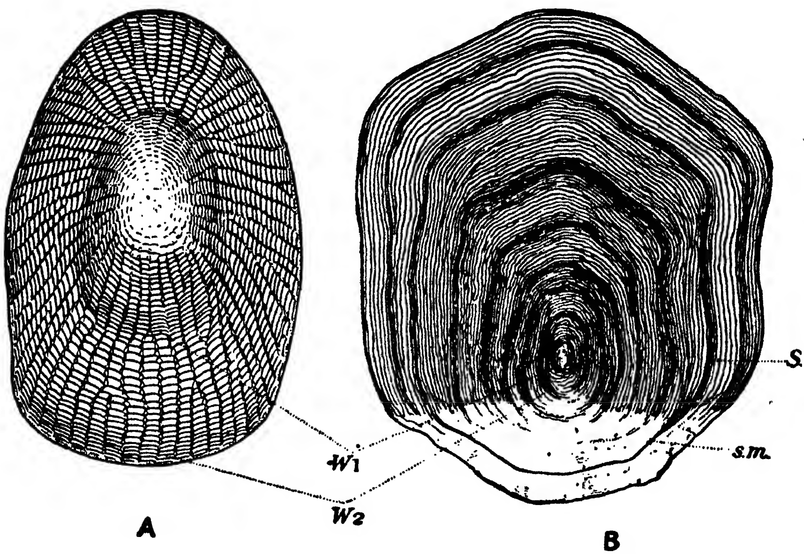


FIG. 85.—Scales of haddock and salmon. (From Graham Kerr.)
W_1, Growth lines of first winter: W_2, Growth lines of second winter.

hollow basal part of the axis is called the **quill** or calamus, the solid distal portion is known as the **shaft** or rachis. At the lower end of the quill is a small hole where the feather fits upon a tiny papilla of the skin (the feather papilla). At the upper end of the quill at its junction with the shaft is a minute opening, and very close to this is a little tuft of barbs. This is known as the aftershaft, and is really the rudiment of another shaft. In the Australian Emu, each contour feather has a double shaft, and probably this is the primitive condition. On each side of the shaft is a 'web' forming the **vane** of the feather. Each vane is

composed of a number of delicate filaments arranged side by side like the teeth of a comb. These filaments are termed the **barbs** of the feather. They can be separated, but it will be noticed that they tend to stick together. It is

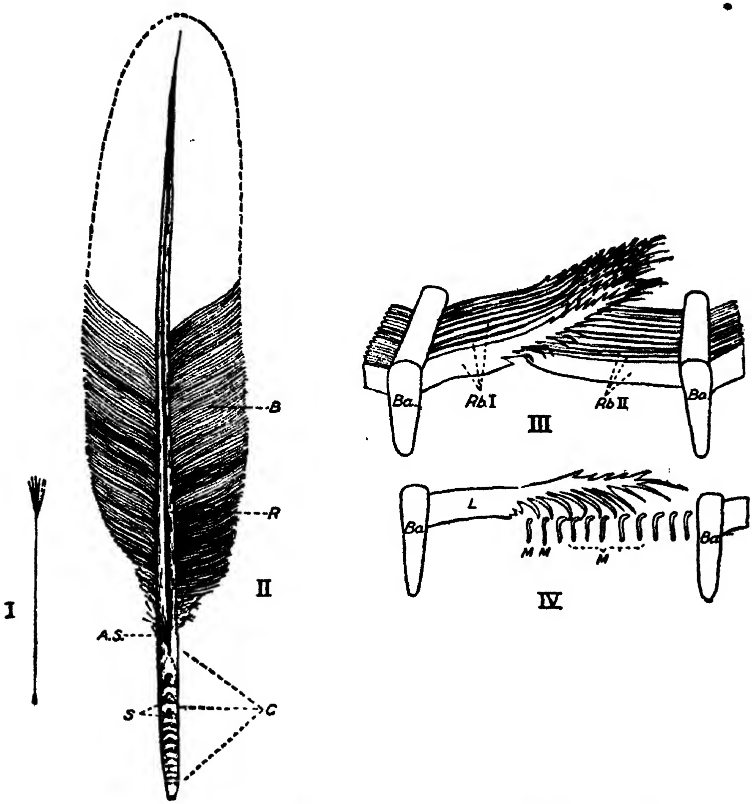


FIG. 86.—Quill feather and filoplume. (From Dakin's *Elements of Biology*.)
I. Filoplume from domestic fowl.
II. Quill feather: *A.S.*, After shaft; *C.*, Calamus or quill; *R.*, rhachis; *B.*, "web" of barbs; *S.*, Septa in quill.
III. and IV. show interlocking of barbs: *Ba.*, Barb; *Rb.*, Barbules; *L*, section of one barbule interlocking with barbules *MM*.

important that they should do so, for without this property the vane would not form a resistant membrane to the air.

Each barb bears a row of delicate processes on either side called **barbules** (observe with microscope, low power, after soaking in spirit). The number of barbs and barbules varies enormously according to the kind of feather (more

than a million barbules have been recorded on one feather). Higher magnification will show that the barbules of adjacent barbs overlap and are held together by small hooklets (see Fig. 86). This is the mechanism which causes the vane to be a resistant structure, and yet strong and light at the same time. In some birds, like the ostrich, where the power of flight has been lost, the barbs do not interlock by hooklets to form a rigid vane, and this is largely responsible for the ornamental character of these feathers. Down feathers lack both the hooking apparatus and the long stiff shaft, the barbs arising directly from end of quill. The feather papillae can continue to produce feathers almost indefinitely, and thus if one is lost or moulted another

Fig. 87.—A down feather.

one will take its place from the same papilla. Moulting is a regular feature, taking place once or twice every year. Frequently when there are two moults annually they take place before and after the breeding season, and the feathers may be unlike, that is, there is a breeding and a non-breeding plumage. There are also feathers which precede the adult types, described above. These are the nestling feathers, of which there may be one or two coats.

Hair of mammals

The structure of the hair of a mammal is shown in Fig. 88. It is formed almost entirely from the outer layer of the skin (the epidermis). It will be noticed that the epidermis forms a downgrowth into the dermis (the **hair follicle**), and from the bottom of this the hair arises, due to proliferation of epidermal cells over the little papilla of dermis which rises into the hair follicle. A little knot of blood vessels projects into this papilla. The hair consists of several layers of cells—a central medulla (the hair is not hollow), a cortex, and on the outside a cuticle of flattened

cells which overlap like tiles of a roof. The colour of the hair is due to pigment in the cells, but whiteness and greyness are usually due to minute air spaces between the cells.

Two root-sheaths of cells surround the hair within the follicle, and near the opening of the follicle there is a little glandular outgrowth—the **sebaceous gland**—on one side, which oils the hair. The hair generally projects from the surface of the skin at an angle, but a few muscle fibres are attached to the hair follicle, and their action may cause the hair to stand on end. This is sometimes occasioned

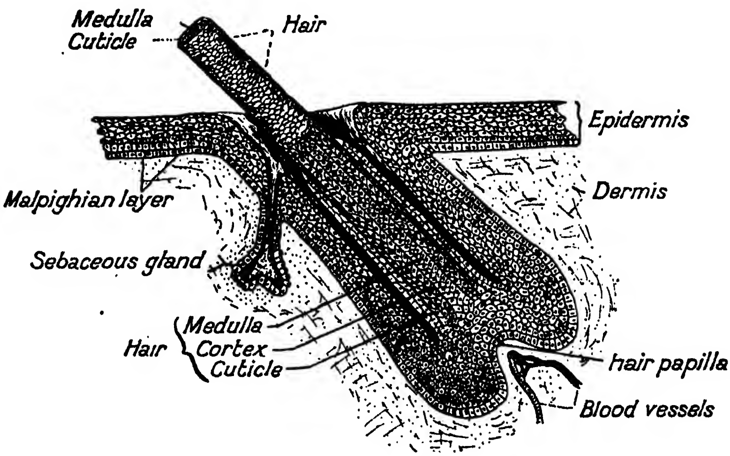


FIG. 88.—A hair and its follicle. (Modified after Kingsley.)

by fright or cold. The power to move the hairs is, however, remarkably developed in some animals—the cat, for example.

Teeth

The lining of the mouth is essentially an in-tucking of the skin in the vertebrates, and consequently it is not surprising to find that teeth are developed from it; as already mentioned, they are closely related to the placoid scales of dogfish (see page 175). In some sharks there is perfect continuity from placoid scales to teeth. The teeth may or may not rest in sockets in the jawbones (part of the endoskeleton). This position is taken up during development in the higher vertebrates. Since, however, the whole of the mouth is lined by skin which may produce

teeth, it is quite natural to find that in some cases teeth occur on other bones of the roof of the mouth (frog and snake).

Teeth were originally and primarily developed to hold the prey, and this is their only function still in many animals (frog, non-poisonous snakes, dolphins, etc.).

In the frog the teeth are tiny sharp-pointed simple cones, each, however, with the typical tooth structure—internal

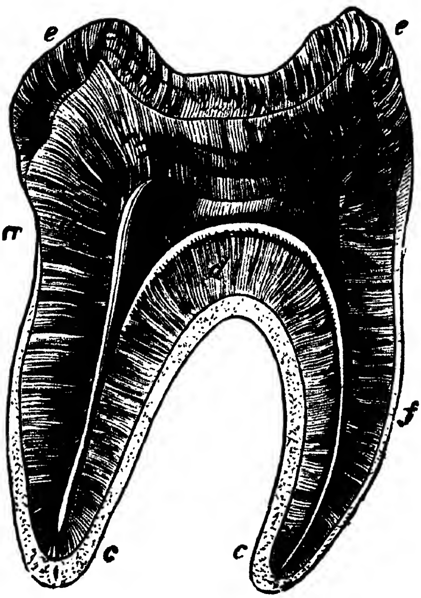


FIG. 89.—Longitudinal section of a molar tooth. (From O'Donoghue.) *k*, crown; *n*, neck; *f*, fangs; *e*, enamel; *d*, dentine; *c*, cement; *p*, pulp cavity.

pulp-cavity with soft tissue, the pulp, wall of dentine and cap of enamel (see Fig. 89). The teeth are all alike, and they are found over the upper jaw and on two bones (the Vomers, and hence vomerine teeth) of the roof of the mouth. There are none on the lower jaws. The teeth have become attached to the bones, but are not in sockets.

As a rule teeth are well developed in reptiles. They are referred to in the description of the skeleton of the head (see page 188).

In birds teeth are never found at all,[1] and this might

[1] Teeth were present in the earliest birds known only from fossils.

possibly be correlated with the unsuitability of their long neck and light bones of the head for carrying teeth, together with the development of a very efficient horny beak.

Mammalian dentitions It is in the mammals that the teeth reach their highest development as far as specialisation is concerned. There is always a close correlation between the feeding habits of an animal and the character of its teeth. It is only exceptionally that the teeth of a mammal are of one type, generally they are varied (**heterodont dentition** in contrast to **homodont,** which is found in dolphins, porpoises and some whales). The teeth are borne in sockets on the jaw margins. The structure is clear from Fig. 89. Blood vessels and nerves enter the pulp, where, in the growing tooth, the dentine-forming cells are found. As a rule the mammalian teeth cease to grow when a certain size is reached, but some teeth (front teeth of rodents, tusks of elephants) are exceptions to the rule. There are two successions of teeth in most of the mammals (in the lower vertebrates there may be a continuous succession—compare with feathers and other skin structures), and these are known as the **Milk** and the **Permanent Dentitions** respectively.

As a rule four kinds of teeth can be recognised in mammals—**incisors, canines, premolars** and **molars.** The incisors are simple teeth in the front of the mouth, the canines are only two in number in each jaw, and usually of conical shape and with a single root like the incisors. The premolars and molars have two or more roots and complicated crowns. The essential difference between them is that the premolars appear in both the milk and permanent dentitions, but only one set of molars develops (permanent dentition).

Since the variations in the types of dentition are important in studying comparative anatomy and systematic zoology, a dental formula has been invented to express the numbers present. This represents one side of the mouth (the other is the same). The dental formula for man is

$$i\,\tfrac{2}{2},\ c\,\tfrac{1}{1},\ pm\,\tfrac{2}{2},\ m\,\tfrac{3}{3},$$

and it means that in the upper jaw and on one side, starting from the middle line in front, there are two incisors, one canine, two premolars and three molars. Below these are similar teeth in the lower jaw. Thus altogether 32 teeth should be present if dentition is complete.

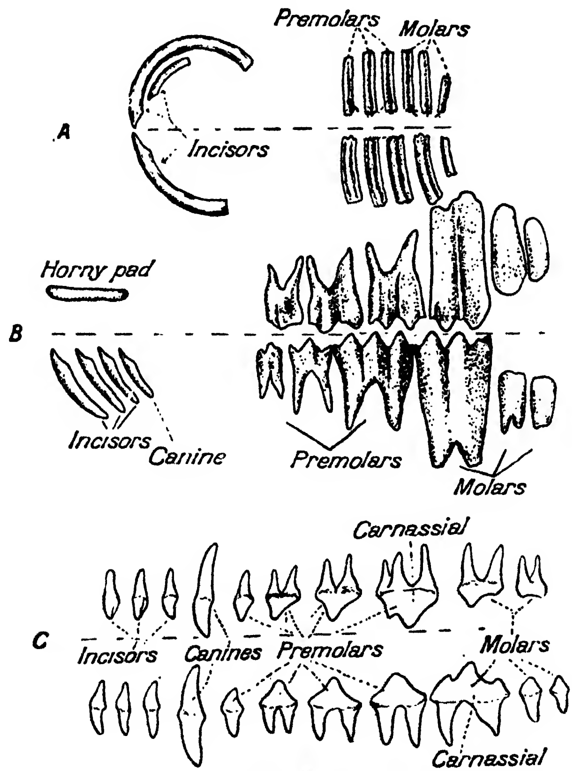


FIG. 90.—Dentition of:
A. Rabbit. *B*. Sheep. *C*. Dog.

In the dog the dental formula is $i\,\frac{3}{3}$, $c\,\frac{1}{1}$, $pm\,\frac{4}{4}$, $m\,\frac{2}{3}$; for the sheep $i\,\frac{0}{3}$, $c\,\frac{0}{1}$, $pm\,\frac{3}{3}$, $m\,\frac{3}{3}$; and for the rabbit $i\,\frac{2}{1}$, $c\,\frac{0}{0}$, $pm\,\frac{3}{2}$, $m\,\frac{3}{3}$.

Dentition of herbivorous mammals

The teeth vary not only in number but in character, so that carnivorous, herbivorous, gnawing and omnivorous dentitions result, and associated with this are differences in the jaw bones, and especially in the hinging of the lower jaw, as will be seen later. An essential feature of plant-eating mammals is that the upper and lower molars and

premolars of either side meet surface to surface, and as a result of a rubbing or grinding motion their surfaces are ground flat. These teeth tend to be alike in size and shape. This is well seen in the sheep, where there are in addition certain special features. In this animal there are neither incisors nor canines in the upper jaw, but a hard pad is developed. The incisors of the lower jaw are crowded together, and project forward in such a way that when they are closed against the pad on the upper mouth surface an excellent vice is formed for grasping and detaching herbage.

Dentition of dog

In carnivorous dentitions the premolars and molars are unlike; they bear one or more points, and are flattened sideways and sharp for tearing and cutting. Frequently two on each side are specially developed—the **carnassials** (see Fig. 90).

In addition to this character the canine teeth are usually well developed, and form powerful weapons for killing the prey.

Rodent dentition

The rodent dentition, exemplified by the rats, mice, beaver and rabbit, etc., presents as the outstanding character long persistently growing incisors, the number of which has been reduced to a pair in each jaw (in the rabbit there are two additional small ones in the upper jaw, but they lie *behind* the other two). These incisors meet when the jaws are closed. Their edges are chisel-shaped, and they remain so as they wear away. They are most interesting teeth, for their persistent growth keeping pace with the wearing away enables them to attack objects of extraordinary hardness.

Associated with these characteristic incisors is the absence of canines and the presence of a gap between the incisors and the grinding teeth. The premolars and molars are developed for grinding or grating vegetable food, and so resemble somewhat those of the herbivorous animals. To complete the story of these dentitions it is necessary to note the jaw movements. This is referred to on page 187 in connection with the endoskeleton.

THE VERTEBRATE ENDOSKELETON

The individual bones of the vertebrate **Endoskeleton** are united together either by **joints** or by a close union, which often becomes a permanent connection by growth of bone (many of the bones of the human skull, which are separate and distinct at birth, fuse together in later life). The joints enable motion to take place, and usually they play an important part in regulating its amount and direction, just as is the case in the Arthropoda, although there are greater possibilities for freedom of movement with this type of skeleton.

Joints and regulated movements

Joints may be divided into **imperfect joints,** where the two bearing-surfaces are so united by gristle or ligaments (bands of white fibrous tissue) that little movement can take place (as, for example, the vertebrae of the human backbone), and **perfect joints,** where there are special arrangements facilitating movement of the one bone on the other. In the latter case the bearing surfaces are perfectly polished surfaces covered with a thin layer of smooth cartilage. The degree of movement possible varies. There are **ball** and **socket joints,** where the head of one bone is a knob working in a cup-like hollow on the other and giving movement in every direction (the hip joint in many mammals is of this kind—also the shoulder). Other joints permit of movement to a more limited extent, such as the **hinge joint** at the elbow (Fig. 81). Movement is limited either by bony projections at the joint or by tying **ligaments** or both. Each joint is enclosed in a **capsule,** which is lined by a membrane which secretes a lubricating fluid.

In the elbow joint of the rabbit, for example (see Fig. 91), the surfaces which move over one another are both lined with smooth cartilage, so that there will be practically no friction. The **periosteum,** the outermost tissue layer covering the ulna, is continued over the joint, and is continuous with the same layer of the humerus. It is in this way that the joint capsule is formed. We can imitate the arrangement roughly by putting two lead pencils end to end and

slipping a piece of indiarubber tubing over the touching ends to form a kind of joint. The capsule not only helps to hold the bones together, but forms a little chamber. This is lined by a delicate membrane called the **Synovial Membrane** (see Fig. 91), which secretes a lubricating fluid. In this way it is contrived that the numerous perfect joints work easily without creating any unnecessary friction to be overcome by the muscles. Sometimes, however, in old animals the cartilage and its lubricating layer become fibrous and the perfect movement fails.

Bones forming joints are held together in position by ligaments as well as by muscles, and it will thus be readily

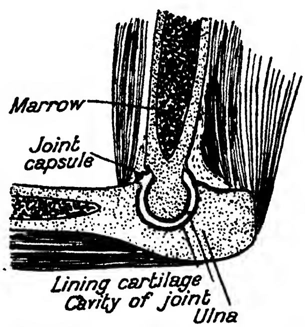


FIG. 91.—Diagram of rabbit's elbow joint.

understood why a bone pulled out of its socket (a dislocated joint) requires a very strong and carefully directed pull to get it back again.

Jaws of Carnivore, Herbivore and Rodent

Variations in joint motility due to structural devices are well illustrated in the jaws of the common types, the dentition of which has just been studied.

The lower jaw moves on the major part of the skull by a hinge joint. Now in the dog and other members of the group of Carnivora it is necessary that the molars and premolars close over each other closely, like the blades of a pair of scissors. In order that they work efficiently (for stripping flesh from bones) it is essential that there should be very little or no side play of the lower jaw (a pair of scissors is very inefficient if the blades do not slide closely over each other). This condition is achieved by the

jointing surface (the condyle) of the lower jaw being not only elongated transversely, but by the corresponding surface on the skull having the form of a deep groove which embraces this condyle of the lower jaw. Thus no lateral 'wobbling' is permitted.

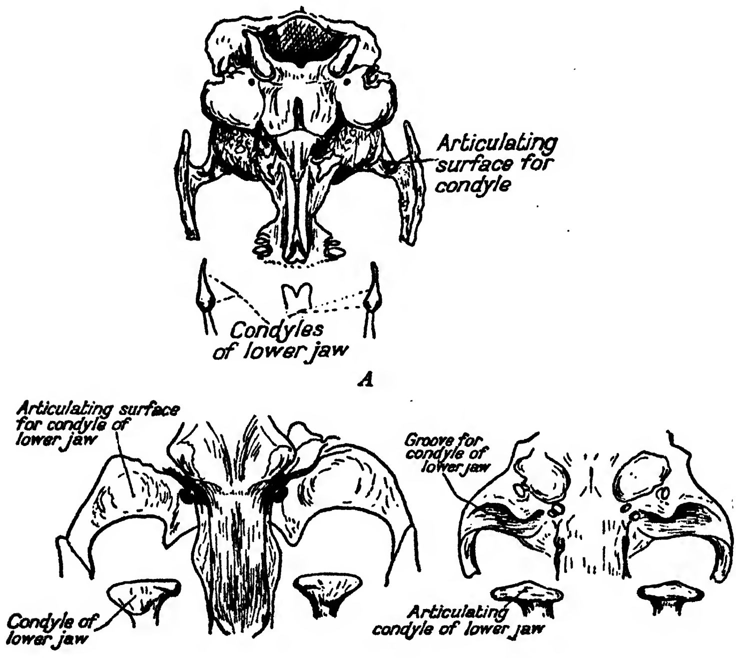


FIG. 92.—Part of ventral surface of skull, showing articular surfaces for lower jaw. The condyles of lower jaw are also shown.
A. Rabbit. *B*. Sheep. *C*. Dog.

In the sheep, on the other hand, the surfaces of the grinding teeth must meet and slide over each other. The jointing of the lower jaw with the skull allows the lateral movement necessary for this; the condyle of the lower jaw is still elongated transversely, but it is not so long and narrow, and it does not fit into an embracing groove on the skull.

In the rabbit the conditions are again different. The lower jaw for the purpose of effective gnawing needs to move backwards and forwards (fore and aft). A glance at

the condyles of the lower jaw (see Fig. 92) shows how this movement is permitted. The jointing surface is elongated not transversely but parallel to the median line of the body.

Skull of snake

An interesting series of modifications of the skeleton fitting in with habits is seen in the skull of a non-poisonous snake, such as the common English grass snake. Snakes usually feed on relatively large prey, and since this is swallowed without mastication or tearing (there are no limbs to hold the prey whilst pieces are torn off), there is need for

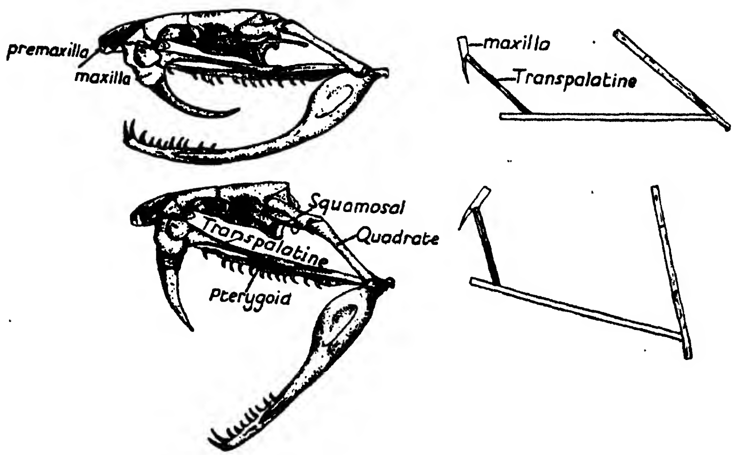


FIG. 93.—Skull of snake having poison fangs. The arrangement for elevating the poison fangs is shown diagrammatically.

a wide mouth aperture. The diameter of the prey is frequently greater than that of the snake's head. Such a thing is possible, because, in the first place, the bones of the upper and lower jaws are mobile, and the two halves of the lower jaw are not fused in front, but are united by a ligament. There are numerous teeth, which are very sharp and point backward like a series of hooks. They are useless for cutting, tearing or grinding, but eminently suitable for preventing slippery prey from escaping. They are actually used by the snake in working its way over the prey. In addition to the features already mentioned, the lower jaw is suspended in such a way that the throat aperture may also be large. This is achieved by bringing the hinge joint far

behind the skull and interpolating an elongated quadrate bone, on each side between the skull proper and the lower jaw joint.

Equally interesting features are visible in the skull of poisonous snakes like the viper.

It is convenient to describe the endoskeleton under the following heads:

The Vertebrate Endoskeleton.

(*a*) The Axial Skeleton { The vertebral column or backbone and the cranium.

(*b*) The Appendicular Skeleton { The skeleton of the limbs and their supports or girdles.

(*c*) In addition to (*a*) and (*b*) there are ribs and breastbone (sternum), and also what is known as the Visceral Skeleton, which comprises the jaws and the gill supports of fishes.

It will be noticed that the skull is a composite structure consisting of brain case and jaws.

The Vertebral or Spinal Column.

This consists of a series of cartilaginous or bony blocks—the **Vertebrae**—which bear an arch above (to enclose the spinal cord) and frequently a similar arch below (the tail portion of the vertebral column in fishes shows this complete). The vertebrae may be all very much alike, as, for example, in fishes and snakes, where there is not much variation in the form of the body, or they may vary very considerably, so that we can recognise neck, thorax, lower trunk, pelvic and tail vertebrae (see Fig. 97). The segmentation of the vertebral column allows for movement to take place in this supporting axis of the body, the amount varying according to the way in which the vertebrae fit against each other. The vertebral column also serves as the basis of attachment of many muscles responsible for locomotion.

In fishes a limited amount of movement is sufficient, and the vertebrae are bi-concave and bound closely together by

connective tissues. In the snakes there are a larger number of vertebrae, up to 400, and these are jointed loosely by ball and socket joints ; one end of a vertebra bears a knob, the other a socket. This permits of the sinuous movements so characteristic of the snake's mode of locomotion.

In the frog the vertebral column must form a more rigid axis, and although the vertebrae are jointed, the reduction

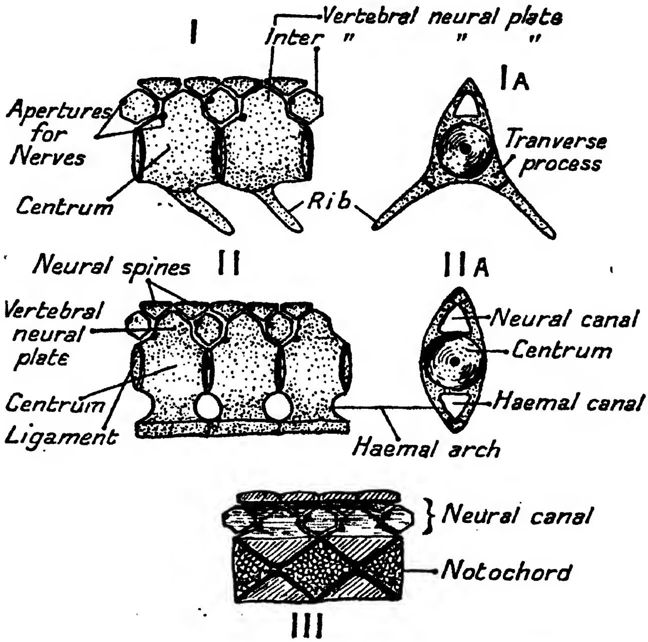


FIG. 94.—Vertebral column of dogfish. (From O'Donoghue.)
I. Lateral view of two vertebrae from anterior region : IA. End view of ditto.
II. Lateral view of two vertebrae from tail : IIA. End view of ditto.
III. Section of two vertebrae.

of the number to nine only and the binding between them prevents much movement (see Fig. 95).

In birds the skeleton is specially modified in connection with the support of the body on two legs only, and also in connection with flight. The vertebral column must form a rigid support, and it has almost lost all power of movement. The individual vertebrae of the trunk region are actually fused together by bone to form one piece, and there is no long tail. On the other hand, to make up for this the

vertebrae of the neck are capable of much movement on each other (each has a saddle-shaped articulating surface), and in some cases the number of neck vertebrae is increased to give additional powers of movement. Anyone who has

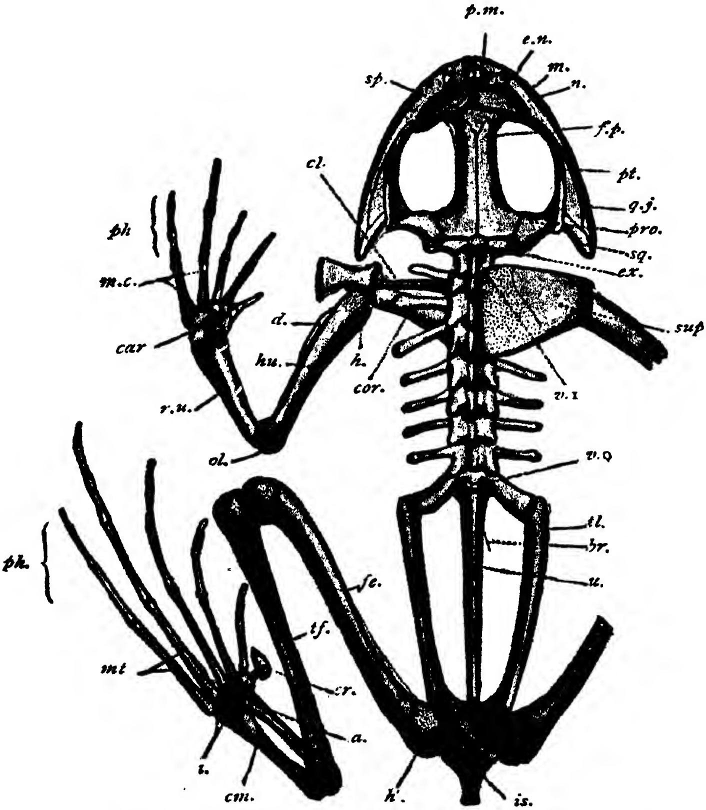


FIG. 95.—The skeleton of the frog. (From Borradaile.)

a., Astragalus; *br.*, bristle passed into opening for last spinal nerve; *car.*, carpal or wrist bones; *cl.*, clavicle; *cm.*, calcaneum; *cor.*, coracoid; *cr.*, calcar; *d.*, deltoid ridge; *e.n.*, external narial opening; *ex.*, exoccipital; *fe.*, femur; *f.p.*, fronto-parietal; *h.*, *h'.*, heads of humerus and femur; *hu.*, humerus; *il.*, ilium; *is.*, ischium; *m.*, maxilla; *m.c.*, metacarpals; *mt.*, metatarsals; *n.*, nasal bone; *ol.*, olecranon process; *ph.*, phalanges; *p.m.*, premaxilla; *pro.*, prootic; *pt.*, pterygoid; *q.j.*, quadratojugal; *r.u.*, radioulna; *sp.*, sphenethmoid; *s.q.*, squamosal; *sup.*, suprascapula; *t.*, distal tarsals; *tf.*, tibiofibula; *u.*, urostyle; *v.*1. first or atlas vertebra; *v.*9, ninth or sacral vertebra.

observed the movements of the neck of the swan will have recognised how great is the flexibility attained in these ways.

In mammals the vertebral column usually forms a bow, which is convex upwards, like some bridges, between the point of attachment of the fore limbs and the pelvic region,

where the hind limbs are attached to the pelvis. As a rule, the body is supported on the four legs, and thus the weight of the abdominal organs is hung from the vertebral column. In man, however, the trunk takes an upright position, and

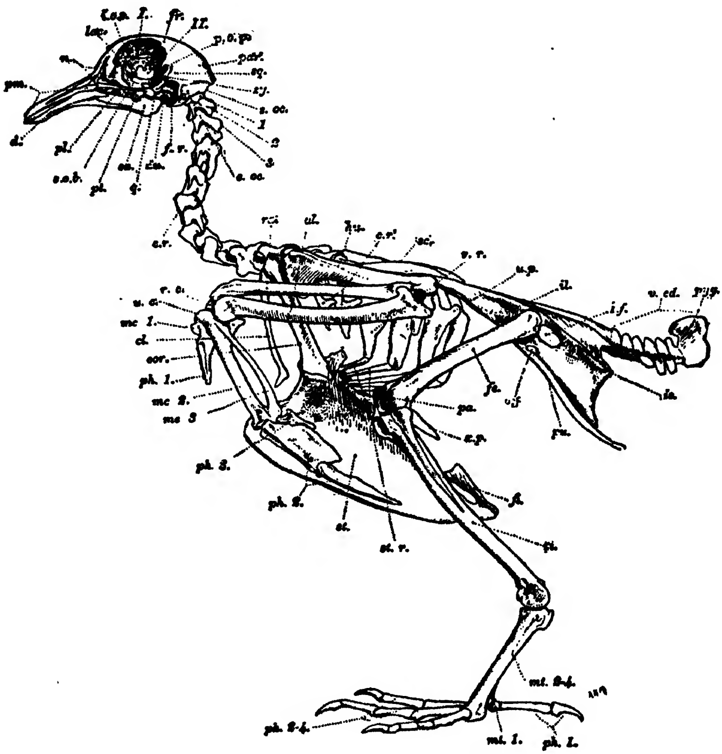


FIG. 96.—Skeleton of bird. (From Borradaile.)
c.r., cervical rib; *cr.*, free cervical ribs; *cl.*, clavicle; *cor*, coracoid; *d.*, dentary; *e.oc.*, exoccipital; *fe.*, femur; *fi.*, fibula; *fr.*, frontal; *hu.*, humerus; *i.f.*, ilio-sciatic foramen; *i.o.s.*, interorbital septum; *il.*, ilium; *is.*, ischium; *lac.*, lacrymal; *mc.*, 1-3, metacarpals; *mt.* 1-4, metatarsals; *n.*, nasal; *o.f.*, obturator foramen; *pa.*, patella; *par.*, parietal; *ph.* 1-4, phalanges; *pl.*, palatine; *pm.*, premaxilla; *p.o.p.*, process of frontal; *pt.*, pterygoid; *pu.*, pubis; *pyg.*, pygostyle; *q.*, quadrate; *r.c.*, radial carpal; *ra.*, radius; *s.oc.*, supraoccipital; *sa.*, supraangular; *sc.*, scapula; *sq.*, squamosal; *st.*, sternum; *st.r.*, sternal ribs; *ti.*, tibia; *u.c.*, ulnar carpal; *u.p.*, uncinate process; *ul.*, ulna; *v. cd.*, caudal vertebrae; *v.r.*, vertebral rib; *x.p.*, xiphoid process; 1-3, cervical vertebrae; I., II., apertures for first two cranial nerves.

this entails modifications and a demand for rigidity again. The vertebrae are not jointed, but between them are elastic cushions—the intervertebral discs of cartilage. These discs bind the vertebrae and also act as shock-absorbers. The vertebrae are clothed with fibrous tissue—ligaments—

and are thus held tightly together, leaving but a limited possibility for movement. In man therefore the vertebrae form a strong column with the ability to twist slightly on itself and also to bend.

The vertebrae in these different groups of animals, and even in one and the same animal, vary in size and shape according to the needs of the part, but all are built on the

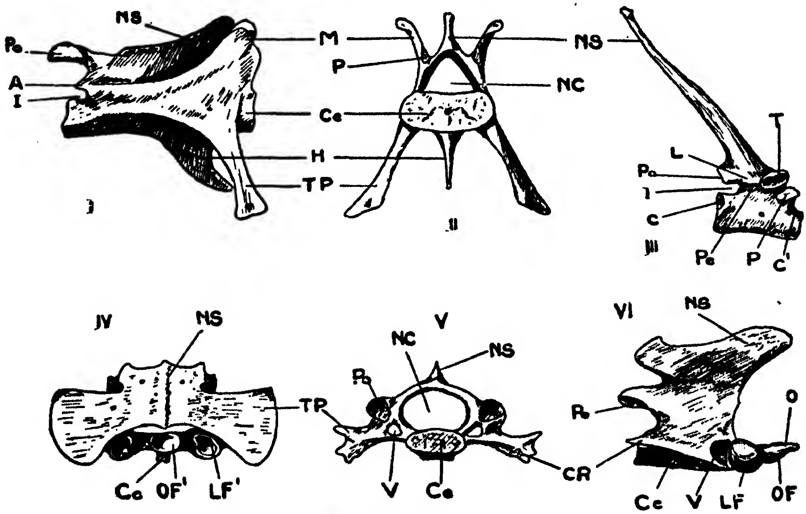


Fig. 97.—Vertebrae of rabbit. (From O'Donoghue.)

I., Lumbar vertebra, side view; II., lumbar vertebra, front end; III., thoracic vertebra, side view; IV., atlas, dorsal view; V., cervical vertebra, posterior end; VI., axis, side view.

A., anapophysis; *C.*, *C'.*, facets for articulation with rib; *Ce.*, centrum; *C.R.*, cervical rib; *H.*, hypapophysis; *I.*, intervertebral notch; *L.F.*, surface for articulation with atlas; *L.F'.*, facet for articulation with lateral surface of axis; *M.*, metapophysis; *N.C.*, neural canal; *N.S.*, neural spine; *O.*, odontoid process; *O.F.*, articular surface on odontoid process; *O.F'.*, articular surface for odontoid process; *P.*, prezygapophysis; *P.O.*, postzygapophysis; *T.*, facet for articulation with rib; *T.P.*, transverse process; *V.*, vertebrarterial canal.

same plan. In fishes only the trunk and tail regions of the vertebral column are differentiated, but in the higher vertebrates the number of different regions is more numerous. It will suffice here to describe the kinds of vertebrae in the rabbit. The seven vertebrae in front of the attachment region of the fore limbs are neck (cervical) vertebrae. The first, the atlas, bears the skull. The second (the axis vertebra) bears a peg which fits inside the atlas vertebra, and so the skull can nod on the first vertebra, whilst skull

and first vertebra together can twist on the peg of the second.

Following the neck vertebrae are the thoracic vertebrae, to which ribs are attached, and then the lumbar vertebrae, which bring us to the region of attachment of the hind limbs. These are jointed to a pelvic girdle or pelvis, and this, as is usual, is firmly attached to one of the vertebrae—the sacral vertebra—which is fused with some of the following ones. About eighteen caudal vertebrae are present, of which the first three or four fuse with the sacral vertebra to form the sacrum.

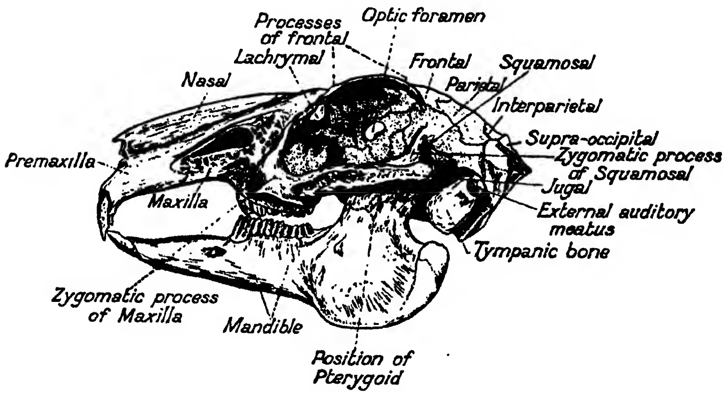


FIG. 98.—Skull of rabbit.

The Skull consists of (1) a bony box (cartilaginous only in the dogfish), the **Cranium**, surrounding and protecting the brain, (2) the skeletal supports of the sense organs (nose and ears) and (3) the **Jaws**. The latter become associated with the cranium, just as the ribs enter into connection with the vertebral column. The jaws are in reality developed from the anterior member of a series of hoops of cartilage which arise in the wall of the alimentary canal in the pharynx region to support the gill slits. In the fishes the other hoops are well developed in the adult, and form the skeleton which supports the gills (and the gill rakers, see page 72). In all the higher vertebrates these visceral hoops, or arches as they are called, become highly modified, and most of them disappear altogether, the traces which are left being

the hyoid or tongue bone and certain cartilages of the larynx.

The shape and size of the cranium is determined chiefly by the extent of development of the brain and the sense organs. In the frog the cavity of the cranium is small, and the two great spaces, where the eyes lie, between the cranium and the sides of the upper jaw give the skull a very characteristic appearance. In the bird (see skull of pigeon, Fig. 96), the eyes are generally extremely well developed and relatively large. The two sockets (the eyes rest in protective sockets of bone) have but a thin partition between them, and the cranium lies in a position altogether behind them. Other characteristic features of the bird's skull are the lightness of the bones, due to air spaces, and the prolongation of the face into a long beak which never bears teeth. **The cranium**

In the highest group of vertebrates, the mammals, there is a great increase in the size of the brain, and this is progressive in the group, culminating in the wonderfully developed human brain. With the increase in size of the brain the cranial cavity increases, and ultimately comes to bulge above the nasal organ, so that the elongated face of the horse, dog, etc., disappears in man with the arching and bulging forwards of the cranium to form a forehead.

The **Ribs** are rods of cartilage or bone which are found enclosing the body cavity, or at least the anterior part of it, as with a cage. They come to be attached to the vertebrae at one end, and they may be attached to a breast-bone, or **Sternum,** in front or end freely. Not only do they form a protection for the organs of the body cavity, but in some cases, for example mammals, they play a prominent part in the mechanism for filling the lungs with air (see page 104), and in the snakes they are directly concerned in locomotion. **The ribs**

The sternum may consist of a number of segments of bone. In the rabbit there are six pieces, but in man fusion of parts has taken place, and the sternum comes to consist of three main parts, the middle of which is the longest and bears marks of four segments which were free **The sternum**

in youth. In the birds the sternum forms the skeletal structure to which the great wing muscles are attached. It is fitted for this purpose, and consists of a large single bone which in the flying birds has a prominent median ridge or keel. This should be familiar to anyone who has seen a turkey or chicken carved. In the snakes there is no sternum at all—it would interfere with movement—and if ribs were attached to it, the great extension of stomach which takes place when a large animal is swallowed would be impossible. In the frog there is a part called the sternum, but this does not correspond to the true sternum or breast-bone of the birds and mammals. It is partly a cartilaginous structure and partly bony, and is closely associated with the pectoral girdle (see below).

The Appendicular Skeleton of the Vertebrates.

This includes not only the skeleton of the two pairs of limbs and their supports, which are known as the pectoral and pelvic girdles, but also the skeleton of the **Median or unpaired fins** only found in the aquatic vertebrates. The supports of the median fins consist in the fishes of a number of cartilaginous or bony rods, each usually divided into two parts and bearing distally horny or sometimes bony rays which support the fin.

Median fins of fishes

Paired limbs

Perhaps nowhere in the animal kingdom does one meet such a host of variations of one fundamental ground-plan as in the limb-skeleton of the higher vertebrates. There is every conceivable variation in size—size of the whole limb and size of the different parts. In some cases the diminution in size goes to such an extent as to lead to absence altogether, as in the snakes (and in the case of the hind limbs of the whale).

Now there are two essential types of paired limbs, and there seems little doubt that they are related, that is, have had a common origin. The paired limbs in fishes have the form of fins, and their skeletal support bears a resemblance to that of the median fins (dorsal, caudal and ventral fins). From the Amphibia upwards, and that means in all the essentially terrestrial vertebrates, it is characteristic of the

limbs to be divisible into three main segments and end in a hand or foot. This type of limb is called the **Pentadactyle** type, because typically there are five digits (fingers or toes). The skeleton is naturally different in the two cases. Fig. 99 represents the **Pectoral Girdle** and **Pectoral Fins** of a dogfish. The skeleton of the fin is rigid, and consists of a number of plates of cartilage supporting a fringe of flexible rods.

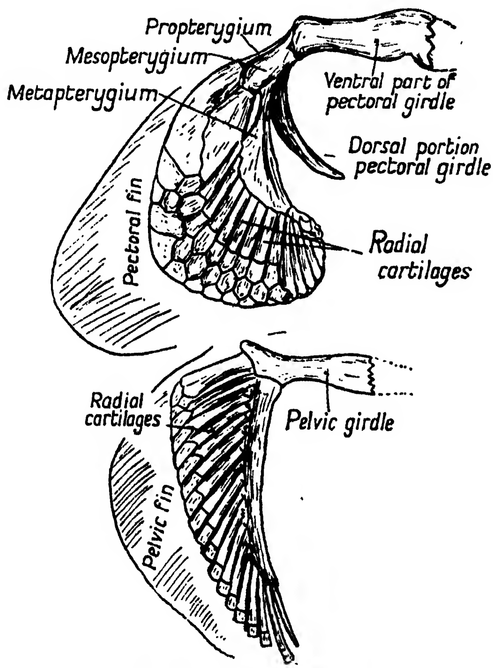


FIG. 99.—Pectoral girdle and fins of dogfish.

Such limbs are adapted to function in a fluid medium as paddles or balancing and steering organs, but not as supports on dry land.

The pentadactyle type of limb evolved with the first terrestrial vertebrates as an appendage suited to support or to push a creeping animal along. The fundamental plan of skeletal structure is shown in Fig. 100, and it will be noticed that it is the same for both fore and hind limbs. **Limb girdles** Each girdle is primarily an inverted arch or U, the convex surface being ventral. It is ossified in the higher

vertebrates, so that typically there are three bones on each side in each girdle (one dorsal and two ventral), and all meet at the point where the limb is attached.

These bones are the **Scapula, Precoracoid** and **Coracoid** in the pectoral girdle, and the **Ilium, Pubis** and **Ischium** in the pelvic girdle. (There is frequently an additional bone on each side of the pectoral girdle, the clavicle—collar bone in man.) The diagram makes the limb bones sufficiently clear.

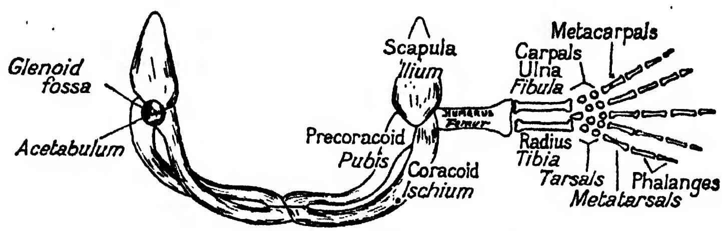


FIG. 100.—Diagram of limb girdles and limbs of a vertebrate.
The uppermost names refer to parts in the pectoral girdle and fore limb.
The lower names refer to the pelvic girdle and hind limb. (After Kingsley.)

It is quite usual to find that the modifications which have arisen are of different degree in the two pairs of limbs, and they are extremely unlike in the birds and bats. But in both these examples the resemblances are greater than the differences. Fig. 101 illustrates the same point, using man and the horse for comparison.

Specially modified Pentadactyle Limbs.

As examples of extreme modification from our fundamental plan we shall take the following common examples—the horse, the sheep, the bat and the pigeon.

Limbs of horse and sheep

The limbs of the horse and the sheep present an excellent example of the modifications which have occurred to facilitate speed in running. We actually know the stages which have taken place, for the ancestors of the horse (found as fossils in the rocks) had several toes, and all the stages leading to the present condition have been discovered. It is a well-known fact that in running there is a tendency to throw the weight of the body on the toes, and in man we

do not put the foot down flat as when walking. Animals which always move on the sole of the foot are slow movers—like the bears (they are said to be plantigrade). In the development of the limbs of mammals for running a series of changes have occurred, so that the toes come more and more into play, and eventually the animals place only the

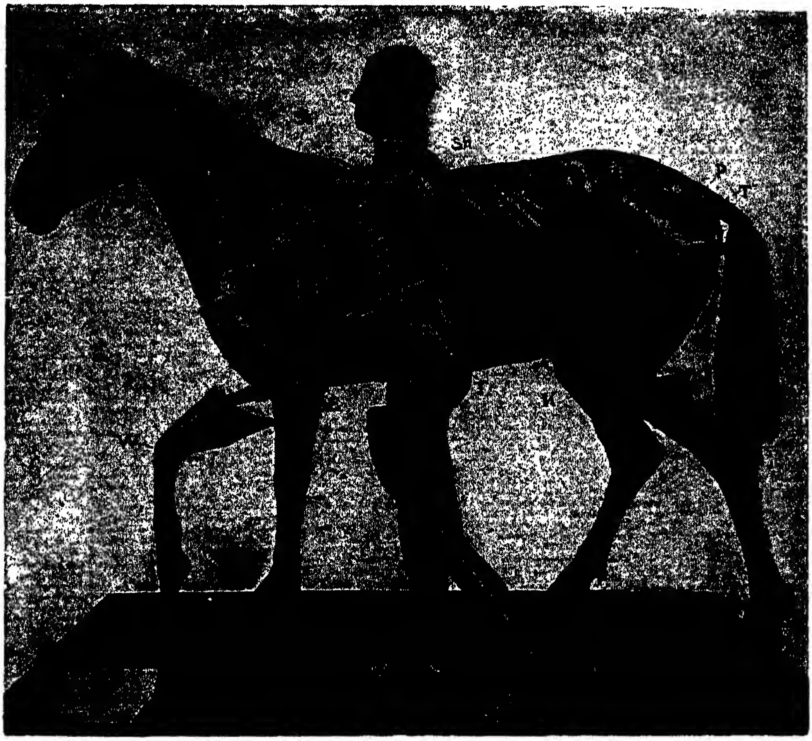


Fig. 101.—Skeleton of man and horse. (From Dendy.)
e., Elbow joint; *h.*, heel bone; *k.*, knee joint; *p.*, hip bone; *Sh.*, scapula; *t.*, tail vertebrae (coccyx in man); *w.*, wrist.

tips of the fingers and toes on the ground. The extreme is reached in the horse and its allies, and in reality the horse may be said to 'walk on its toe nails.' At the same time a reduction in the number of bones of the hand and foot has taken place.

This has proceeded in two different ways. In the horse the axis of the foot runs down through the third toe, and reduction of toes has taken place until this is the

only perfect one left in each foot, although traces of the second and fourth still remain as splint bones. The end joint of the toe is enlarged and invested by a horny hoof. In the sheep (also ox, pig and deer) the axis of the limb runs down between the third and fourth toes, and consequently reduction of toes tends to leave only these two (resulting in the cloven hoof), although faint traces of the others may be found. Note also the fusion of the two bones of the second division of the arm and leg (radius and ulna, tibia and fibula, respectively) and lastly the position of the parts which give springiness to the whole.

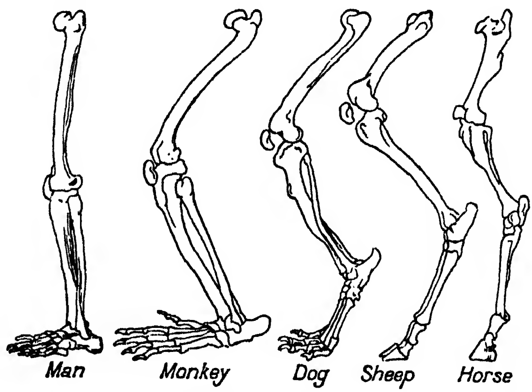


FIG. 102.—Leg skeleton of man, monkey, dog, sheep and horse. (From Borradaile after Le Conte.)

Wing of bat

The Bat is the only mammal which flies by raising and depressing a wing, and with this is to be correlated several peculiarities in the skeleton which is modified in relation to flight. Most obvious is the production of a supporting skeleton for the wing membrane by elongation of the arm bones, and more especially by enormous elongation of the fingers. Since the shoulder requires strong support the clavicles are well developed, and for attachment of powerful muscles there are large shoulder blades, and the bones of the sternum are not only fused together, but the sternum bears a crest (cf. bird's skeleton).

Limbs of bird

We have already seen that the skeleton of the bird is a much modified version of our fundamental plan, and that this is associated with flight and also with the support of

the body when standing on the two hind limbs only. Before describing the limbs it should be pointed out that many of the bones of the bird's skeleton are extraordinarily light; they are often hollow and many contain air spaces. This is particularly true of the long bones of the limbs.

The limb girdles may first be noted. The connection of the arms (modified as wings) with other parts of the skeleton must be strong. We find that the head of the arm bone fits into a socket formed by three bones—the shoulder

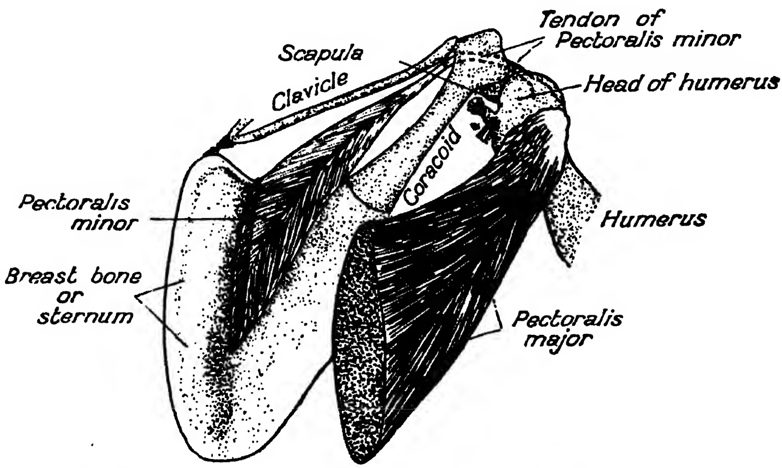


FIG. 103.—Diagram of side of sternum of pigeon with shoulder joint and course of tendon of pectoralis minor muscle which raises the wing. (The ligaments binding the bones together are not shown.)

blade (scapula), the coracoid and the clavicle or collar bone. All are well developed, especially the coracoids, which connect with the breastbone. This is a great contrast with the rabbit skeleton.

The pelvic girdle consists of the usual three bones on either side, but these are all fused together in the adult and also fused with a considerable number of vertebrae, so that a peculiarly shaped structure results. The pelvis is always very large. The net result is that the legs are more directly connected with the backbone, and a firm support for a standing bird is the result.

The same parts may be distinguished in the wing of the bird as in our generalised type—the upper arm (with its

single bone, the humerus), the lower arm with two bones (radius and ulna) and then the wrist and hand. It is the latter part which is peculiar. Only three fingers remain, the bones of which are reduced in number, and in the adult they are all fused together (see Fig. 96).

Muscles of bird's wing The muscles which raise and depress the wing are both attached to the same bone (the humerus) and their other ends also to a common support—the sternum. How is it possible then for one to elevate, the other to depress? If the two great wing muscles be carefully dissected off one side of the sternum and then carefully followed to the shoulder, it will be found that whilst one tendon is attached to the under side of the humerus, the other passes through a hole (the *foramen triosseum*) formed at the shoulder joint, and thus practically over a pulley, to be eventually inserted on the upper side of the humerus (see Fig. 103). Pulling on these muscles one should be able to move the wings in the appropriate directions. Here is an excellent example of the use of the skeleton for changing the direction of pull of a muscle.

The hind limb of the bird presents interesting modifications too, according to its adaptation for walking, swimming, grasping and so on. The bones are indicated by Fig. 96. The foot is better developed than the hand, but it will be noticed that considerable fusion of ankle bones has taken place.

Practical work on the skeleton (1) Examine the exoskeleton of the crayfish, lobster or crab. Note the continuity at the joints and the continuation of the skeleton inwards to line the alimentary canal. Examine joints of appendages.

(2) Preparation of chitin. Chitin, the essential substance of the Arthropod skeleton, can be freed from other substances deposited within it (lime salts, etc.) by leaving for some days in dilute hydrochloric acid (several times renewed). Wash with running water and boil in 10% solution of caustic potash. Wash again, and if using crayfish skeleton treat once more with dilute HCl. To remove pigment use dilute solution of potassium permanganate and wash this out with sodium bisulphate. Wash with

distilled water. Chitin is a nitrogenous substance insoluble in water, alcohol, ether and concentrated alkalis. It is soluble in concentrated sulphuric and hydrochloric acids.

The change in colour of a lobster (or crayfish) when boiled is due to the presence of a pigment which is unstable and easily changed into the red state by various treatments.

(3) Examine the appendages of a number of arthropoda, including the cockroach, Dytiscus and the hermit crab, and note the amount of movement allowed at the joints.

(4) Examine different types of exoskeleton. Scales of herring under microscope for lines of growth. Placoid scales of dogfish or ray (cf. with pages 174 and 177). Note distribution and types of feathers on common pigeon. Study details of quill feather with low power of microscope. Examine sections of mammalian skin for hair. Make careful comparison of dentition of fish, frog, rabbit, dog or cat and sheep. Note also movement possible in lower jaw of these animals. Study section of tooth.

(5) A study should be made of the skeletons of the dogfish, frog, pigeon or common domestic fowl, rabbit, bat and man. Diagrams of most of these are given, more detailed descriptions may be found in numerous text-books.

(6) Examine in particular the types of joint in the vertebrate endoskeleton. Dissect out the knee joint and thigh joint of a rabbit. Saw through the joints and note the capsule (see page 185).

(7) Examine skull of snake and note special features, allowing wide gape, etc. (cf. page 188).

XI

MOVEMENT OF ANIMALS

MUSCULAR ACTIVITY. LOCOMOTION

Movement of animals in general

It is characteristic of animals in general that in their adult stages they have the power to move from place to place. This is in great contrast to the plants which are usually fixed organisms. There are some exceptions in the animal kingdom, such as the sponges, many coelenterates like the corals, some bivalve shellfish, barnacles and other creatures which attach themselves and live fixed to rocks or other objects. But in all these examples the parts of the animal are capable of some movement, and although there are flowers which open and shut and even plants which move when touched, this type of movement is relatively poorly developed in plants and is produced in an entirely different manner.

We have already seen something of the methods adopted in the lowest organisms, where locomotion is achieved by a flowing of the protoplasm (pseudopodia) or by the lashing of permanent little cell structures like cilia and flagella. In the higher animals cilia are also found, but in general the remarkably diverse mobility is dependent upon the action of a special tissue—muscle. In fact, practically all animal movement is either pseudopodial, flagellate (including ciliate) or occasioned by muscle cells. The latter are cells in which the protoplasm has become specialised in regard to contractility in one direction, and this specialisation is accompanied by the development of tiny fibrils which run through the cell. The first beginnings of the muscle cells amongst our examples are seen in *Hydra*, but delicate fibrils which are endowed with special contractility are first developed in the protozoa (*e.g. Euglena* and *Monocystis*).

Let us glance at the features of animal life which are correlated with this character of movement. We have seen that animal nutrition is characterised by the necessity for complex foods which can only be obtained from other living things—animals or plants (dead or alive). This of itself means movement, for animals must move to places where their food is situated and they must capture it, or if they are fixed (like those referred to above) they must waft their food towards them.[1] This locomotion which is the result of a primary necessity—the need for food—sets up other developments in its turn. It results in animals being more or less bilaterally symmetrical and having an end which generally goes first, and is termed the anterior end. It emphasises the need for a system of sense organs to enable the animal to discover food and to direct itself instead of depending on chance or accidental contact with the desired substance. Again active search for food may result in active competition between animals for its possession, and consequently there is need for the power of flight, of the tricks and devices of concealment and of the weapons for fighting. Representatives of the animal kingdom which live a sedentary life do not offer us anything encouraging in the way of example. 'A rolling stone gathers no moss'—it remains clean and bright!

This searching for food may mean the limited range of the tiny protozoon in its puddle or the looping of *Hydra* over little more than this range. On the other hand, we have ranges of thousands of miles which are traversed by whales and more regularly by birds. The following up of food often means existence for a period in areas which are not altogether favourable for other reasons. The browsing ruminants feed in the open, where they may be exposed to carnivorous animals from which their only hope is flight. Therefore they move off to more sheltered places as soon as possible, and hence have developed that remarkable habit of swallowing a large quantity of food and then

[1] Parasites may be an exception to this and possibly some protozoa, but even in these forms there is characteristic movement.

bringing it back again to the mouth to be chewed at leisure (chewing the cud).

Animal migration

The shore-loving worms live in a zone where food is particularly plentiful—the area which lies between tide marks. They have, however, in many cases to move down with the tide or to burrow down in the mud when the tide goes out. This is an example of a movement which has become a regular rhythm. The movement of migratory birds is a seasonal one from place to place. It is not exceptional, although none the less wonderful. The eel and the salmon perform equally wonderful migrations, the eel going from the European rivers thousands of miles to the deep waters of the Western Atlantic to breed, whilst the salmon enters fresh waters and overcomes the swift currents of rivers in its endeavour to reach the breeding grounds. Numbers of other marine animals perform difficult migrations, although probably not of such a remarkable character.

But this introduces us to another factor. In plants and animals it is characteristic that reproduction should commence with the union of two cells produced by the reproductive organs. In plants these cells are most frequently brought together by outside influences, such as wind and water or by insects (the carriage of pollen). In animals the reproductive cells *may* be brought together by water (as in some aquatic animals), but even in these cases it is often essential that the animals producing the sex cells be close together at the time. And thus locomotion is linked up with the reproductive process. Fishes often come together in shoals at the breeding season. Others pair and travel together to suitable breeding places.

One of the most fascinating studies in plant life is the means of dispersal of seeds. The dispersal of seeds is necessary to plants to prevent overcrowding at the place where they are produced. We meet with the same distribution in the animal world. Actively moving creatures travel, ever spreading further from the region where they were produced so long as conditions of environment allow. Thus we have that awful calamity—the rabbit in Australia.

The animal was introduced into Eastern Australia by someone who knew not what would follow. Rabbits have gradually increased and spread until the whole continent—even the hot and inhospitable dry central region—has been crossed, and they have invaded Western Australia, where rabbit-proof fences have had to be erected by the Government and where a Government Department is responsible for destroying the pests. The European sparrow introduced in the same way is doing the same thing. It also is crossing that wide continent. Generally distribution in this way is most easy for birds and marine animals. They have fewer boundaries than land animals, which may be stopped by rivers, seas or mountains.

There are many animals which have not this locomotory power of distribution—the fixed bivalve shellfish, the slow-moving crustacean, the sponges, the corals, the sea slugs, the starfishes and sea urchins. Their distribution is in some respects like that of the plants. Their young stages are active swimming and floating larvae, which are carried by the sea and ocean currents rather than transported by their own directive efforts far from the place where they are produced.

Muscle movements (Limb muscles)

Finally, reference might be made to some of the most wonderful muscle movements man is capable of—the beautiful powers of the ballet dancer, the pianist, the violinist and the painter. In fact, our most ingenious locomotory inventions—the aeroplane and the motor car—are a long way behind the natural world. We have only to think of certain sea birds which not only have great powers of flight, but can walk, swim and dive as well, or of the graceful chamois leaping from rock to rock. The characteristic source of all these movements in the animal body is the specialised structure, the muscle fibre.

A good example of the development of a contractile structure in a cell is to be seen in some of the cells of the outer layer of a Hydra. These cells are known as musculo-epithelial cells (see Fig. 38). Each one is roughly conical in shape with the broad end directed outwards. The narrow inner end is produced into one, two, or more long

processes which run at right angles along the body wall in a longitudinal direction and help with others to form a layer. It is in these processes that the living protoplasm has specialised in the direction of contractility, and it is the regulated action of these cell processes which enables Hydra to change in shape, to wave its tentacles and to move (see below for details).

Muscles and their action

The typical muscle cell is much more specialised and wholly devoted to its particular function, and with many other neighbouring muscle cells is bound up to form muscular tissue or **Muscles.** But all muscular tissue is not of the same kind. There is great diversity according to the function, type of contractility to be performed and the type of animal. Roughly we divide it into three

FIG. 104.—Smooth muscle cell (unstriped muscle).

classes, but one of these classes is only made to include the *heart* muscles of *vertebrate* animals (**Cardiac Muscle**). The most widely distributed, and probably the lowest type, consists of fibres which are elongated cells containing a single nucleus, a mass of protoplasm known as **Sarcoplasm** and a number of fibrillae running longitudinally through the cell. This is known as **Smooth** or **Unstriped Muscle,** for a reason which will be clear presently.

Smooth or unstriped muscle

In vertebrate animals unstriped muscle has become restricted to parts which are not under the control of the will. It is the muscle tissue of the viscera (the alimentary canal wall, the blood vessels, etc.). Thus it is sometimes known as involuntary muscle in this group of animals. The name, however, is not altogether a good one, and in any case the heart muscle is involuntary, but it is striated muscle. The highest type of muscle is made up of fibres which are distinctly cross striped. It is found chiefly in the vertebrates, where it is limited to the muscles producing movements of the skeleton, to the eye muscles, and those of the ear, the diaphragm, the tongue and skin in some cases:

in short the muscle which is under the control of the will. **Striped Muscles** are, however, also found in other animal groups. They are particularly well developed in the Arthropods—the wing muscles of insects, for example—and they are exceptionally found in molluscs (in the scallop, for example). The fibres of cross-striped muscles are difficult to place at first sight, for each fibre contains several nuclei, although not divided by cell walls. Each fibre begins, however, as a single cell (Fig. 105, *B*, *C* and *D*). Then, as it grows, the nucleus divides, but no cell walls

Striped muscle fibres

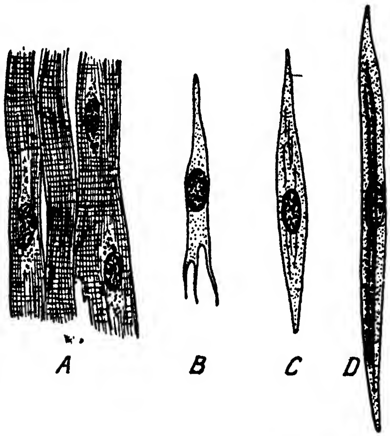


FIG. 105.—*A*. Cardiac muscle, showing striations and intercalated discs. (Modified from Jordan.)
B, *C* and *D*. Stages in the development of a striped muscle fibre. The nucleus is still undivided in each of the stages depicted. The fibrils appear in *C* and the cross striping is visible in *D*. (After Heidenhaim.)

appear and so eventually a long coarse fibre is produced. A structure of this kind, where many nuclei are found in a mass of protoplasm, is known as a **Syncitium**. (Fig. 106 *C*.)

Each muscle fibre of a striped muscle is bounded by a delicate wall—the **Sarcolemma.** Within this is the **Sarcoplasm** containing the real contractile elements, the **Fibrils.** And it is the fibrils which give the character to striped muscles. They consist of alternating segments or granules of a different nature. There are several types of striping, but we need not go into them here.

Heart or Cardiac Muscle of vertebrates (not of other groups) is quite a distinct type. It is made up of a kind of

Cardiac muscle

meshwork through which striped fibrillae run. It is often regarded as consisting of distinct peculiarly-shaped cells (see Fig. 105, *A*), each with a single nucleus, but it is better to regard it as a meshwork of sarcoplasm with nuclei and with fibrils running through it, for what were once thought to be cell boundaries are really bands which do not extend completely through a fibre.

These differences between muscle fibres are correlated with their differences in action, and whilst many problems are still unsolved it is clear that striped muscles are present where rapid contraction is required.

The actual time taken for contraction by a smooth muscle fibre of the frog's stomach has been calculated at so much as 10-15 seconds, and by a striped muscle of the same animal at 0·049 second, but the speed of contraction of the muscles of insects' wings must be as little as $\frac{1}{500}$th of a second or even less.

Unstriped muscles are therefore suited for slow but sustained action. This is well seen in the scallop (a shellfish which can clap its shell valves and thus swim). The large muscle which runs across from one half of the shell to the other consists of two parts. One of these is unstriped, and serves to close the shell and keep it shut, whilst the other is striped and is responsible for the 'clapping' movements.

Structure of a vertebrate limb muscle

Now let us look at a striped muscle as a whole, taking a voluntary muscle such as the biceps of the human arm as an example.[1]

The muscle swells out in the middle and narrows towards each end, where it is attached by tendons to the bones. (One end of such a muscle is frequently known as its **Origin** and the other as its **Insertion**, but the names are not of great consequence, and the term origin does not indicate that the muscle originates there.) The muscle is covered by a dense elastic membrane, the **Epimysium**, and from this partitions are given off which divide the muscle into bundles called **Fasciculi.** Each fasciculus is surrounded by

[1] The word muscle is sometimes used to denote muscular tissue (*i.e.* a piece of muscle) and sometimes to denote one definite collection of muscle fibres forming a distinct unit.

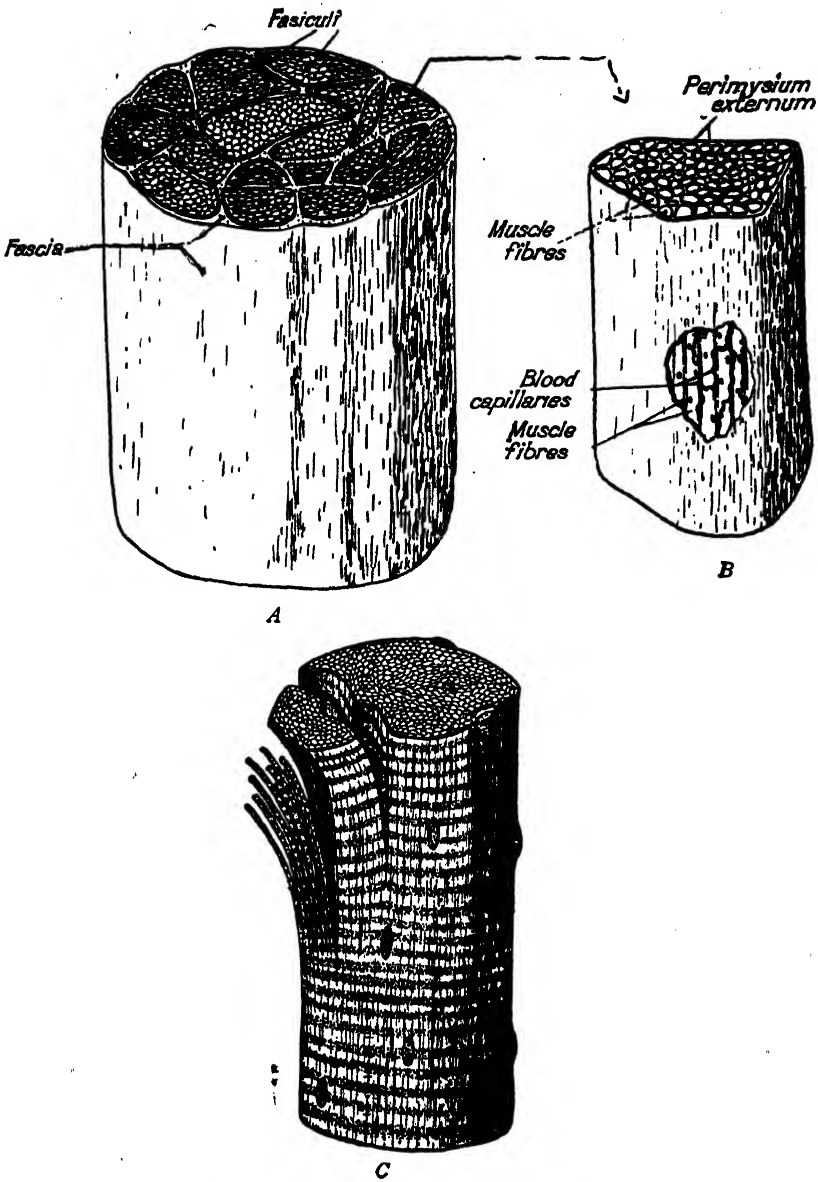


Fig. 106.—Diagram showing structure of a voluntary muscle. *B* is more highly magnified than *A*, and *C* much more highly magnified than either.

A. A piece of voluntary muscle composed of fasciculi covered by a sheath or epimysium (fascia).

B. One of the fasciculi enlarged (note that it is a collection of muscle fibres and that it is surrounded by perimysium).

C. A single striped muscle fibre highly magnified. (Modified after Goldschmidt.)

its sheath, known as **Perimysium.** Then each fasciculus is a bundle of muscle fibres, each surrounded by delicate connective tissue (**Endomysium**). Thus we come to the muscle fibre with its sheath or **Sarcolemma** and its contained **Sarcoplasm** and **Fibrillae.** In addition to all this there is within the muscle a network of nerve fibres with endings on the muscle fibres and networks of blood vessels with capillaries surrounding the muscle fibres. Equally important, however, and too often forgotten is the presence of little 'receptors' or sense organs for taking up *stimuli*, and from these nerve fibres pass out of the muscle.

Tendons are strands of tough whitish fibre without the power of contraction. They are characteristic attachment

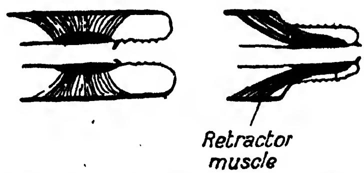


FIG. 107.—Diagram showing extrusion of proboscis of a worm by compression of fluid of body cavity. (After Lang.)

structures, and it is often easier to break a bone than a tendon.

Mechanics of muscle

Muscles may build up a contractile structure without being attached to any framework or firm skeleton. This is seen, for example, in the foot of shellfish like the snail and limpet, and to a certain extent in the lips of a mammal.

In other cases of a similar nature the action of the muscles depends upon their working on a closed cavity full of fluid. Thus the protrusion of the proboscis of a marine worm is due to the contraction of muscle fibres which press on the fluid in the body cavity. As the fluid is incompressible a pressure is set up which is utilised for the purpose stated.

Most of the complicated and beautiful movements of animals are, however, due to muscles which have some fixed point of attachment at one or other end. In the case of the insects and crustacea this, as we have seen, is a hard

shell of chitin on the outside of the animal, and the muscles are attached to the internal surface. In the vertebrate animals, the skeleton being internal, the attached muscles may be said to clothe it (see Figs. 80 and 81).

Animal joints actuated by muscles form levers, and just as there are different orders of levers in mechanics, each with certain advantages and disadvantages, so we find different systems in the animal body. Three possibilities are shown in Fig. 109.

The attachments of muscles are therefore not necessarily where the muscles' *power* may be utilised to best advantage.

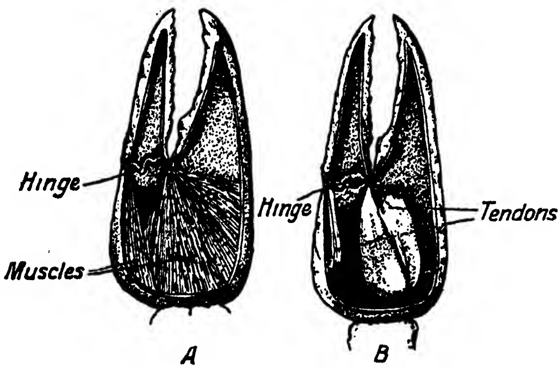


FIG. 108.—Chelae of crayfish.
A. With one surface cut away to show muscles of end joint.
B. Muscles stripped away to show tendons to which they are attached.

Something else, that is, speed of movement, may be required. The muscle which raises the human fore arm is attached in such a position that it could raise 24 lbs. at its attachment place as easily as 1 lb. in the palm of the hand. But it raises the single pound weight in the palm 24 times as fast, owing to the position of its attachment.

Regulations of muscle activity

The complicated and beautiful nature of animal movement in the higher types is due to the number of muscles which may be brought into harmonious action at the same time. Fig. 110, for example, gives some idea of the tendon attachment of muscles in the paws of the rabbit. One can take this as an example which may be practically examined. It will serve as a reminder of the complication present in

the human hand and the power of control which is achieved by great violinists and pianists.

It must be realised here that the muscles in the animal body are almost always arranged in opposing sets. The contraction of the circular muscle fibres, which makes an earthworm become more slender, and in consequence greater in length, is accompanied by the relaxation of the muscles which run along its length. The contraction of the wing muscles which depress the wings of a pigeon is accompanied by the relaxation of the muscles which raise the wings. It has been calculated that upwards of 300 muscles are involved when a human being takes a single step. It must be

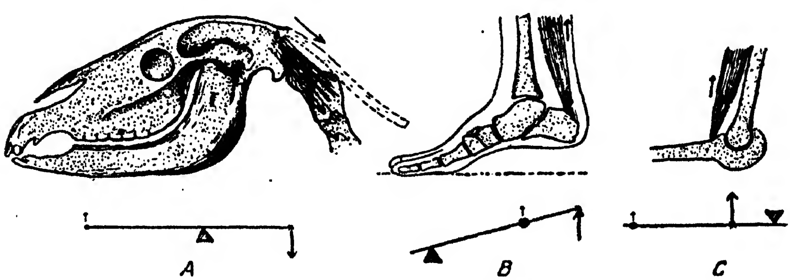


Fig. 109.—Three types of levers.
A. Head of horse. Lever 1st order. *B*. Human foot. Lever 2nd order. *C*. Elbow joint. Lever 3rd order.

obvious that very careful adjustment and control of these muscles is necessary in order that they work in such harmony as to produce the wonderful results to which we have drawn attention. The control and the balancing of the actions of different muscles is not due solely to the nerve messages sent into the muscles from the sense organs on the surface of the body. It is largely due to messages sent from one muscle to another, picked up by those often forgotten internal sensory receptors in the muscles themselves. It is, for example, in this way that opposing muscles are brought into relationship with each other.

In only a few cases do muscles pull against some elastic tissue which is responsible for the complete antagonistic action. Thus the shell of the cockle and other bivalves is closed by the action of adductor muscles which draw the

two halves of the shell together. In so doing a piece of elastic ligament at the hinge line is either compressed or extended (some bivalves work one way, some the other). In either case relaxation of the muscle results in the shell automatically opening, and hence dead oysters may always be distinguished by the shells remaining open.

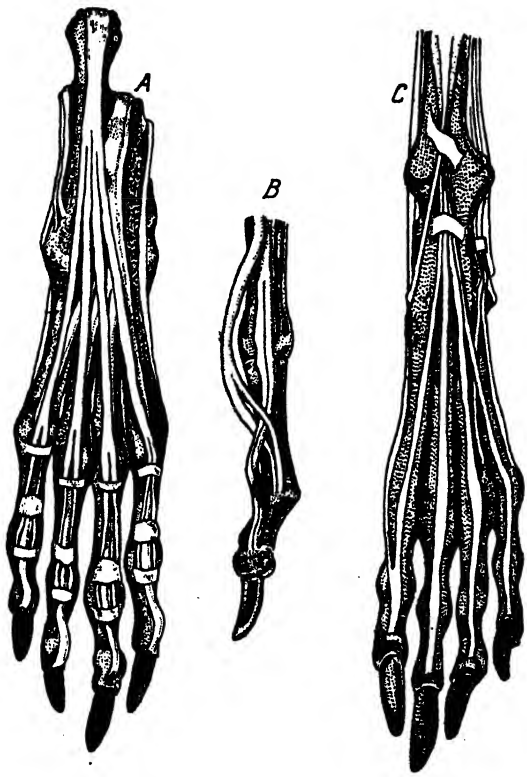


FIG. 110.—Tendons of foot of rabbit.
A. Left hind foot from underneath. *B*. Third toe seen from below.
C. Left hind foot from above. (After Röseler and Lamprecht.)

A muscle contracts as the result of the contraction of its constituent fibres and the muscle fibres contract as the result of stimuli received from nerves. These not only initiate contraction, but regulate its speed. We can imitate this stimulus by electricity—an electric shock (impulse) applied to a nerve connected with a living muscle will cause that muscle to contract. It has also been shown **Physiology of muscle**

that muscle fibres will contract as the result of direct stimulation with electricity independently of its entering by way of a nerve fibre. Of course other stimuli will cause nerve and muscle to react, just as we found that *Paramecium* and *Amoeba* would react to chemical, mechanical and other physical stimuli, and in the body of higher animals there are definite organs where nerve cells are specialised to respond to these different stimuli. Electric stimulation is much used in physiological studies of nerve and muscle, and it is interesting to note that the contraction of muscles as the result of an electric stimulation played a great part in the discovery of electricity, and consequently in the history of modern electrical invention.

Galvani, Professor of Anatomy at the University of Bologna (1737-1798), discovered electric currents through the intervention of a frog. He observed that the leg muscles contracted smartly when brought into relation with a metal conductor composed of two metals such as zinc and copper. His explanations of the reaction were not correct, but they aroused the interest of Volta and led to the most far-reaching results.

When a nerve impulse passes into a muscle there is a short period before contraction takes place. This is known as the **Latent Period.** It is supposed that during this time certain chemical changes occur which have the effect of putting the contracting mechanism into action. The latent period is very brief, for isolated frog's muscle less than $\frac{1}{100}$th part of a second. However, it varies in an interesting manner under different conditions. We cannot detail here the various theories of muscle contraction. The fact remains that notwithstanding all we have discovered about the structure and chemistry of the muscle fibre, there is so far no really satisfactory explanation of the mechanism of contraction. In fact it is only in the last few years that we have begun to understand some of the chemical changes.

It is well known that if muscles are kept contracting and relaxing (working) for a time, an inability to continue this gradually sets in. We speak of it as **Fatigue.** Fatigue may

be experimentally illustrated by a simple experiment with an **Ergograph** fitted up in the way shown. It consists of a rest for the arm and an arrangement whereby the middle finger on contracting lifts a small weight (Fig. 111).

Fatigue

If the time between two contractions of the finger be kept constant, it will be found that the contractions become gradually less and less powerful, and eventually the weight cannot be lifted at all. After a rest, however, the muscles of the finger are able to continue again. Whatever caused fatigue has disappeared during this interval. It is possible in this very

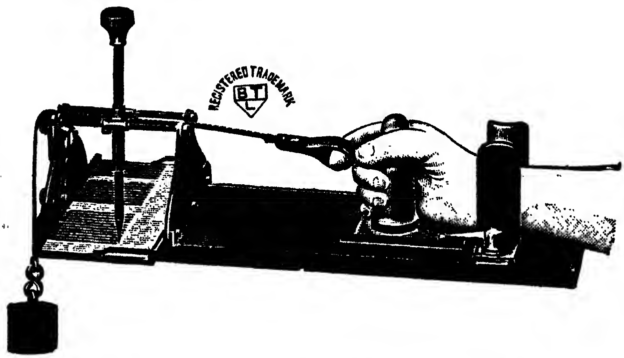


FIG. 111.—Ergograph for recording work done by a finger.

simple way to experiment under varying conditions, and it is found that fatigue is influenced by the condition of the body—general health, hunger, loss of sleep and so on.

Fatigue is largely due to the accumulation of the products of muscle action, and thus a period must elapse during which these products are removed. We have already emphasised the fact that energy in the living cell is obtained by oxidation of substances built up by the protoplasm from the food. It is natural, therefore, to find that an active muscle produces carbon dioxide, and the slightest change in the amount of muscular activity of an animal increases the output of carbon dioxide.

Chemistry of muscular contraction

From recent discoveries it would appear that the chemical changes in an active muscle fall roughly into three periods:—(1) The period of contraction, (2) the period of relaxation, and (3) a period of recovery. It is common knowledge that muscular activity is associated with the production of heat.

The experiments to which we referred above show that not only is heat produced when each muscle fibre contracts, but also on its relaxation and during the period of recovery.

Recent very brilliant biochemical research has shown that Muscle Contraction is accompanied by a surprisingly complex series of chemical changes in the muscle during which Glycogen, the raw material for muscle energy, is converted through a whole series of organic compounds in which phosphoric acid is involved, till finally *lactic acid* results. This is the end product of a muscle contraction and no combustion, *i.e.* no oxidation, has taken place accompanying it. The energy set free by these chemical changes is thus obtained in a manner quite different from what was originally accepted, viz. the belief that fuel substances were oxidised like the burning of petrol in a motor.

The accumulation of lactic acid is, however, a hindrance to a repetition of the changes in the muscle we have just mentioned ; it must be removed, and this involves oxidation and more heat production. So the lactic acid is oxidised and burnt to Carbon dioxide and water. But the energy so produced is considerable and a most interesting feature of muscle chemistry results therefrom. The oxidation of only $\frac{1}{5}$th of the lactic acid produced is sufficient to provide enough energy to convert the remaining $\frac{4}{5}$ths back to glycogen again, ready to take part in another muscle contraction. These processes are constantly repeated. It is obvious, however, that if there is a continuous burning of some of the lactic acid during continuous muscle activity, there must be a constant supply of carbo-hydrates to the active muscles, a constant supply of oxygen, and the removal therefrom of carbon dioxide. A good blood supply is thus essential.[1]

If the muscular activity is of moderate amount, that is, the kind which may go on for long periods without producing fatigue, the normal oxygen supply will be sufficient to oxidise the lactic acid as it is produced. But it is possible for animals to make great temporary muscular efforts which cannot be met by the normal oxygen supply. During these bursts of energy the lactic acid accumulates in the muscle and eventually stops its action. An oxygen debt has been incurred, and a little time will now elapse during which respiratory exchanges greater than the normal will take place until the lactic acid has been removed and the carbon di-oxide expelled. This is taking place, for example, during the period of panting which ensues after an athlete has made a great effort.

In all probability fatigue after prolonged activity is not only due to the products of the muscle activity, but also to the insufficiency of the material (probably glycogen) which

[1] This is not the complete story of muscle contraction, but it is all that we dare attempt to relate here of a very complicated chemical mechanism.

is acting as the source of energy. We have already seen that this substance is stored in the tissues and especially in the liver. *Rest* means both the restoration of the destroyed materials and the removal of waste. There are other details, but we cannot enter into them here.

Muscle Tone. This is a feature of living muscle which is additional to its conditions of relaxation or contraction. It implies a kind of continuous but slight contraction which keeps the muscle tight and ready for contraction. It is like the finger which is pulling, or perhaps better only feeling, the trigger of a gun ready to pull hard at a moment's notice. Muscle tone is dependent on nerve control, and it is affected greatly by the health of the body.

Power of muscles

The force exerted by the muscles of an animal is by no means inconsiderable. The absolute power is not always obvious however, because, as we have seen, the muscles are not always attached in the most efficient position for its manifestation.

It would almost appear as if there were very great differences in the power of the muscular tissues of different animals, especially of insects. There are differences, but these are not necessarily as great as would appear from mere observations of animal movement. Thus, for example, a bee has been shown to exert a force equal to 24 times its weight, and the jumping power of the flea is well known to all. This superiority is not due to the greater efficiency of the individual muscle fibres. Small animals as a rule are capable of greater leaping efficiency than larger animals. As an animal increases its size its weight increases as the cube of its body length. But the sectional area of the muscles only increases as the square of the length. Thus the larger the animal the greater the weight of the muscles in comparison with their sectional areas. The strength of the muscle is, however, proportional to its sectional area (and the number of its fibres). It is clear, therefore, that the athletic efforts of the flea and other small animals are due to the larger proportion of the muscle fibres to the weight to be lifted. Expressing the situation in figures, if two animals were as 1 : 2 in length, then the

weights would be in the proportion 1 : 8, but the muscle power only in the proportion 1 : 4. The matter is by no means quite as simple as this, and other factors probably result in the weight being relatively greater in large animals than is indicated by these figures.

Exercise and muscle condition Before passing to study movement in various types, we may conclude this section by reminding the reader of the effects on muscle of use, of exercise. The muscle becomes bigger, more efficient, and the movement is more easily performed. The increase in size takes place as in growth. The muscle fibres enlarge, and more fibrillae appear in them through the splitting of those already present. Movements are performed more efficiently, not only because of the increase in the power of the muscle, but because the muscles are trained. Each one acts just to the extent required, and those whose action is unnecessary do not interfere as they did perhaps at first. The degree of control possible is naturally also a question of the efficiency of the nerve centres.

Rigor mortis Finally we may mention that peculiar condition which causes stiffening of the body of animals a short time after death. It is due to the death of the muscles and the coagulation of the protein of the muscle substance. The muscles all shorten as a result and hold the limbs rigid. After a time other changes occur in the protein, it breaks down; the flesh, that is the muscles, once more becomes tender and *rigor mortis* passes away. These changes explain why a fowl which has been cooked too soon after killing may be quite tough!

Animal locomotion **Illustrative types**:—*Hydra*, Earthworm, Crayfish, Mollusc, Insects aquatic and flying, Fish swimming, Frog jumping, Bird flight, Man standing.

Hydra is capable of slow change of position by what are practically pseudopodial movements of the basal attachment disc. Attached at one spot, however, it can explore quite an extensive range owing to its power of extension and contraction and the movement of its tentacles. All these movements are conditioned by the muscular processes of the cells of the outer and inner layers. Those of the ectoderm cells run in a longitudinal direction. The

shorter muscular processes of the endoderm cells run in a circular direction, and between them contraction in various directions is achieved. A more rapid locomotory movement known as Looping is from time to time made use of. In this the *Hydra* extends its body and bends it so that the tentacles come to touch a neighbouring spot a little distance away. The tentacles then hold on whilst the basal disc is lifted and brought up close to a new point of attachment nearer the tentacles (Fig. 112, *A*). The process is then repeated. The movement can be more rapid still if the *Hydra* brings its basal disc right overhead and extends it far to the opposite side. This movement looks like a series of somersaults (Fig. 112, *B*).

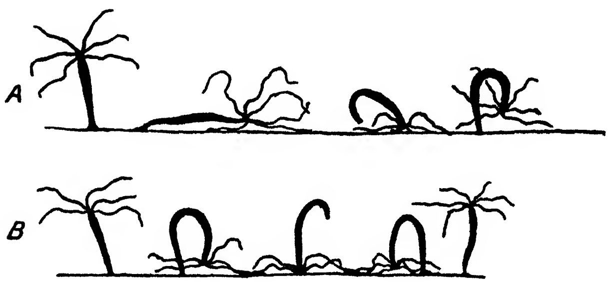


FIG. 112.—*Hydra.* Diagram illustrating methods by which the animal moves from place to place. (See text.)

Earthworm

The movements of the earthworm depend upon the tube of muscles forming the greater part of the body wall. There are two layers, one of muscles which run round the animal—**circular muscle fibres**—and the other and more internal of **longitudinal muscle fibres** which run 'fore and aft.' Other structures involved are the little chitinous bristles, the **setae,** of which there are four pairs projecting from every segment except the first and last. These are embedded in little sac-like intuckings of the epidermis to which muscles are attached. The result of this is that the setae can be slightly withdrawn, or they can be projected and directed either forwards or backwards.

Locomotion takes place as follows:—A section of the body (the anterior part, for example) is elongated and stretched forwards by the contraction of the circular

muscles which press on the fluid of the body cavity and reduce the diameter of the animal. The setae are then extended and kept projecting backwards to hold the fore part, whilst the longitudinal muscle fibres contract (the circular ones in the meantime relax) and thus reduce the length of the worm. Since the front part is held firmly by the setae, the hinder part must be pulled forwards when the contraction in length takes place. An earthworm could move backwards in a similar manner with the aid of the setae. Other slower creeping movements are possible,

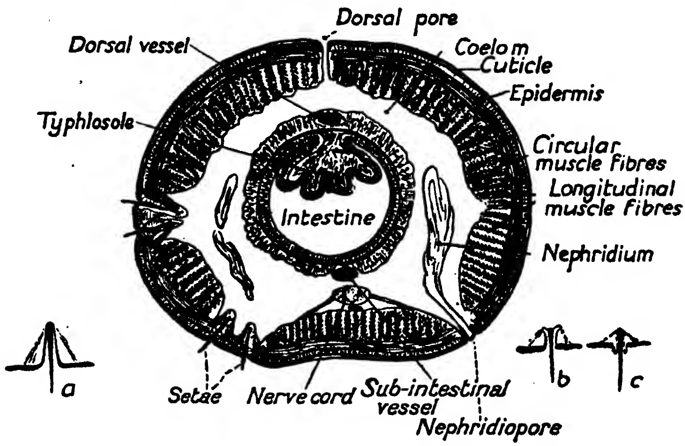


FIG. 113.—Diagram of transverse section of earthworm. *a*, *b*, and *c*, Setae, (various degrees of protrusion).

in which the alternating elongation and contraction does not take place and the worm moves somewhat like a snake.

The snail

Many people who have watched an ordinary snail or slug moving along on its foot, take the action as something characteristically animal and do not think about the details. Few could explain how a soft muscular mass, which seems in contact with the ground along its whole length, could glide forwards. The matter has excited the interest of naturalists for many generations. Some of the pond-snails can not only glide up a surface like the glass of an aquarium, but they can also glide with the same organ, the foot, on the surface of the water—*but on the under surface and suspended from it.* If a snail be caused to

walk over a moist glass plate, it will be noticed by looking underneath that, whilst the foot remains everywhere in contact with the glass, a series of waves (as many as 8-12 perhaps) moves from the posterior end forwards. This movement is due to a complicated series of contractions and relaxations of the muscle fibres composing the foot. At the same time the snail exudes a quantity of mucus from the gland at the anterior edge of the foot. This is its track, and is an aid to adhesion. How the waves accomplish locomotion is much more difficult to investigate and explain. It is now believed that, at any one moment, the foot is resting on the surface over which the snail is crawling at a few points only. Wherever there is a wave the foot is lifted away from the substratum, and these parts

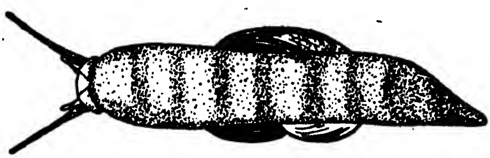


FIG. 114.—Foot of snail crawling on glass plate, as seen through the glass.

move forward. Therefore the whole gliding motion is the sum total of a series of little shifts forward of parts of the foot. Each part of the foot in turn moves forward as it is lifted free from the surface adhesion.

The crayfish is an example of a group of animals, the crustacea, which show a more varied series of movements, and correspondingly we meet with a much more highly organised system of muscles and lever-like joints (see Fig. 79). The locomotory muscles are attached to firm supports. Two modes of locomotion are possible. Crayfish live in little holes which they make in the banks of small rivers or even ditches. During the brighter part of the day they remain in their holes with only the tips of the great claws and long feelers (antennae) projecting. When they come out they crawl slowly, using the four pairs of **Walking Legs,** which touch the ground one after the other in a definite order. If they are startled they retreat **Crayfish**

backwards very quickly by sharply striking forward (and at the same time bending underneath them) the end of the abdomen. The hindermost appendages of the body, which are flattened and spread out to form a kind of fin (often called a **Tail Fan**), expose a large resistant surface to the water.

There are other appendages which are concerned in locomotion. These are the **Swimmerets** (see page 479) on the abdomen. They move rhythmically like paddles, and probably aid the crayfish in its forward movements when walking. Smaller Crustacea like the shrimp and prawn swim actively by their aid.

Insect movement

The range of habitation of the insects is so wide that we must limit our examples to a swimming insect and a flying insect. Running and jumping insects, like the cockroach and grasshopper, move their limbs in a manner similar to the walking limbs of a crayfish.

The *Culex* larva (gnat or mosquito) is heavier than water, so that it sinks to the bottom by its own weight. It swims upwards with a wriggling motion by striking rapidly with the tail. A swimming movement is achieved here without the aid of special appendages; although one cannot say that the results are very efficient, they suffice for the habits of the larva.

The most active swimming among the insects is achieved by the water-beetles. We may take *Dytiscus* as an example. The shape of the animal is well suited for movement through the water. The swimming organs are the legs, but it is the hind legs which are specially adapted for this purpose. They are flattened, and one edge is fringed with a series of stiff hairs so as to act like oars. The resemblance in action is still more complete, because the terminal segments rotate slightly when the leg is moved, so that the broad face sweeps the water during the stroke and the edge during the return. The middle legs also aid in the swimming movement, but these, in particular the front legs, are much smaller and the fringe of hairs less developed.

The fore legs of the male *Dytiscus* are peculiar in that they bear large and powerful suckers. These, however,

are not concerned with locomotion, and are therefore not described here.

Dytiscus swims on its ventral surface, and its air supply is collected and carried on its dorsal surface under the elytra. Another swimming insect, *Notonecta* (the Water Boatman), swims on its back, but the reason for this may be seen in the fact that its air supply is situated ventrally, and this surface is therefore most light.

Insect flight

The mechanism of insect flight is less complex than that of the birds, owing chiefly to the comparative simplicity of structure of the wings. It is, however, extremely complicated. Flight is due to the active movement of the wings, which are really flat folds of the external cuticle of the

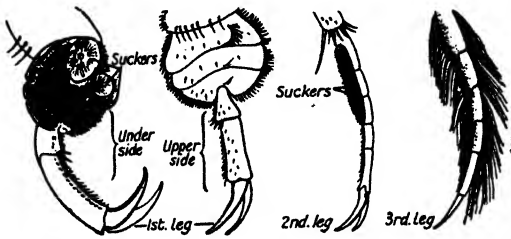


FIG. 115.—Tarsal joints of 1st, 2nd, and 3rd legs of Male *Dytiscus*. (The suckers are only present in the male sex.)

body. There may be two pairs of wings or only one pair. When there are two pairs they may both take part in the up and down movements, or the hindmost pair may do this whilst the front ones are stretched out, generally at right angles to the body, and act almost like the planes of an aëroplane. When the insect is at rest the fore wings may act as cases for the protection of the hind wings, which lie folded beneath them. This type is most frequently met with amongst the beetles. On examining an insect's wing such as that of the housefly or bee, it will be seen that the front edge is thickened and supported by firm chitinous 'veins,' whilst the hinder edge is more delicate. The result is that when the wing is brought down, the pressure of the air causes the hinder part of the wing to give, and hence to be deflected upwards. The wing thus strikes

obliquely, and consequently both supports and drives the insect forward. When the wing is raised the deflection is in the other direction.

In the resting position the bee's wings cover each other. For flight they are first moved into what may be termed the flight position, which means that they are turned until the front margin makes almost a right angle with the rest of the body. At the same time a row of hooks (*hamuli*) on the front margin of the hind wing interlocks with a

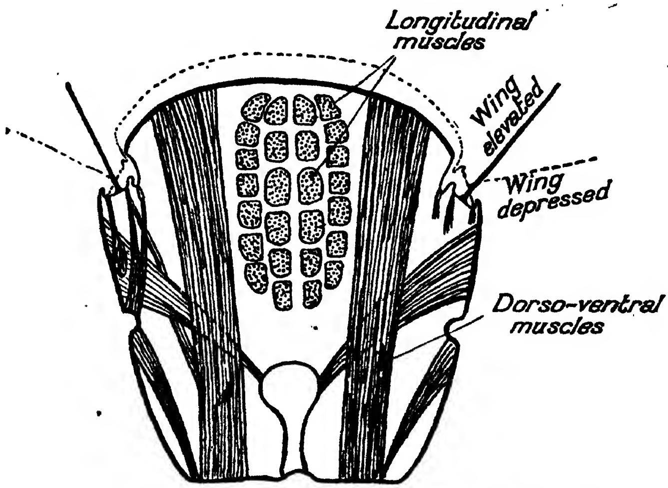


FIG. 116.—Transverse section through thorax of an insect, showing the chief muscles which produce movement of the wings. (After Janet, from Hesse and Doflein.)

strengthened fold on the hinder margin of the fore wing, so as to give practically one flying membrane on each side of the body. (The wings of moths are often held together in a somewhat similar manner.) The wings now move rapidly up and down, the extent being almost a semicircle, and the tips of the wings almost touching when they are at their highest point.

The number of vibrations is somewhere between 200 and 400 per second.

There is now the problem of how the wings encounter as little resistance from the air as possible when they are being raised. This is achieved by twists of the wings in

such a way that, on elevation, the fore wing practically cuts the air with its front edge and the obliquely placed wing surface exposes as little resistance as possible, whilst when the wing is lowered the whole surface comes into action. All these movements are produced by the rapid and rhythmic contraction of muscles in the thorax of the insect. It is here that the complexity lies and the muscular apparatus is brought into relation with the insertion of the small but strong wing roots on the sides of the thorax.

It is a striking fact that the flight muscles of insects are of two categories—some (direct) are attached to the wing

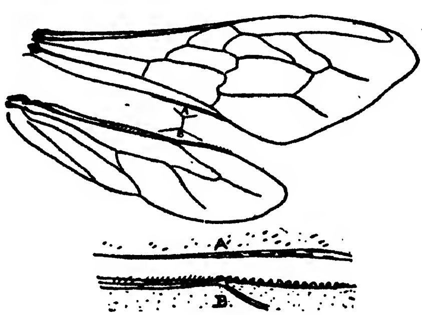


FIG. 117.—Wings of honey bee.

root, others (the indirect) are not attached to the wings. In most insects it is the latter which are chiefly concerned in the important up and down wing movements. Some of them run from the roof of the thorax to the ventral surface, whilst others run longitudinally. By the contraction of the latter, the form of the thorax is altered (as indicated in Fig. 116), and this movement alters the position of the wing base so that the wing is depressed. Contraction of the muscles running dorso-ventrally elevates the wings.

It is unfortunately impossible to describe in greater detail the beautiful system of levers at work here, or to explain how our knowledge of such actively moving parts has been obtained. Probably the advent of the slow-motion cinema will provide us with another instrument for this kind of work.

Swimming of fish

Fish, with certain exceptions (slow-moving fishes like the tropical coffer fishes), present the most highly adapted locomotion in water. The shape of a herring, mackerel or goldfish is admirably fitted for swift movement in water. The thickest part is in front of the middle, and the width diminishes gradually to the tail. This is recognised by engineers as a shape which is 'streamlined,' and likely to produce the least resistance. The transverse section of such a fish has the form of an ellipse, whilst that of a torpedo is circular. But this increase of height over width in the fish is accentuated by the dorsal and ventral fins, and we may regard it as a definite means for preventing a kind of side slip which is likely to be set up by the locomotory action of the tail with its powerful lateral movements.

The essential swimming organ of the fish is the tail, which at rest presents a *vertical* surface bearing a **fin**—a delicate fold of skin supported by a series of little rods, the fin rays. The tail of the fish is more than a mere prolongation of the vertebral column, indeed it is often impossible to draw a bounding line between tail and trunk. Not only is the tail capable of a wide range of movement, but muscles attached to the base of the fin rays produce wave-like flexions of the fin itself. In rapid swimming the tail is flexed to one side and then brought back with a jerk, to pass then to the other side from where the motion is repeated. This is easily seen. It is not so easy, however, to make out the details nor to understand why this movement should force the fish forwards. The swing of the tail back from the side to the middle line will force the fish forwards and slightly to one side, but the initial movement of the tail outwards to the side should produce an opposite type of movement, that is, backwards. Since, however, resistance in water to movement varies as the square of the speed of the moving object, it is possible to understand the tail action if the movement away from the middle line outwards is slow compared with the rapid jerk back to the middle line. This is combined with other complications—the movement of the caudal fin itself and the swirls set up in the water. Thus the tail fin in its movements resembles

much more the screw-like twist of a ship's propeller, if we could imagine one that could rotate first one way and then the other producing a forward movement each time.

There are other fins on the fish, but, except in special cases, these play only a small part in forward movement, except when the fish is moving along very slowly. (The pectoral and pelvic fins may then be actively functional as swimming organs.) The dorsal and ventral fins aid, as we have seen, in keeping the fish on a straight course. The paired fins play a much more conspicuous part in balancing

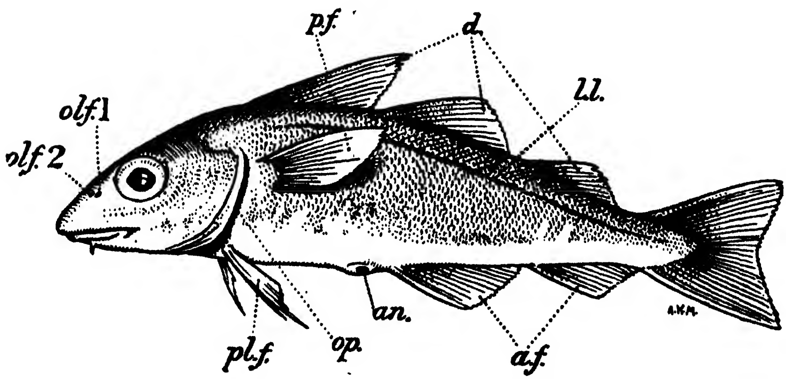


FIG. 118.—A bony fish—the haddock. (From Graham Kerr.) *a.f.*, anal fins; *an.*, anus; *d.*, dorsal fins; *l.l.*, lateral line; *olf.* 1 and 2, olfactory openings; *op.*, opercular opening; *p.f.*, pectoral fin; *pl.f.*, pelvic fin.

the fish. That balancing organs are necessary is demonstrated in many cases where death is immediately followed by the fish turning belly upwards or lying on its side.

Mention is not made above of fish movements such as those of fish living on the bottom, like plaice or rays, or other peculiar types. In the rays, the tail has been much reduced as a swimming organ, and its function taken over by the great pectoral fins which form the lateral expansions of the body. These perform undulatory movements.

It has been usual to recognise two types of flying in birds: (1) the type of flight in which the wings make upward and downward movements, and (2) soaring or sailing flight where the wings are kept extended like those Flight of birds

of an aeroplane. It is quite impossible to enter into the more minute details of the movements involved here, for it is evident that much remains to be discovered. Until quite recently the long-continued movement of birds in the air without any flapping of the wings was altogether a mystery. Now it has been shown that man can perform the same thing in small aeroplanes without engines at all by making use of wind currents. In fact, it has been possible to sustain the human body with plane apparatus and sail about for upwards of several hours. Probably

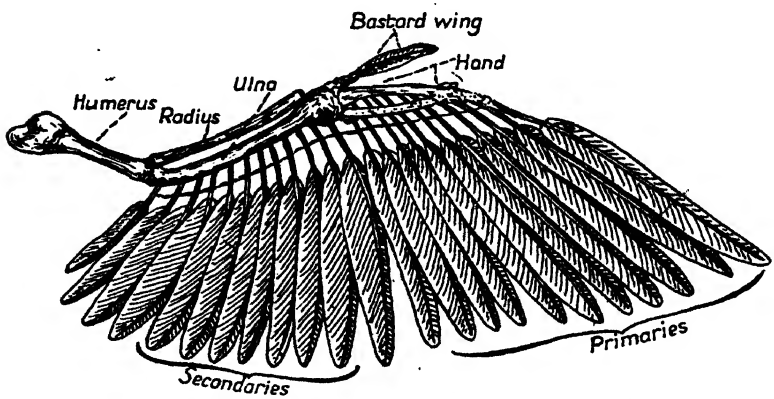


FIG. 119.—Diagram of wing of pigeon seen from below. The covert feathers from the base of the quill feathers are not shown.

(Note how the wide half of vane overlaps the narrow half of vane of adjacent feather so that by downward movements of wing it is supported by the shaft of the latter, and the wing is thus made air resistant.)

this aeroplane-like action of the wings under the deliberate steering and control of the bird plays a part also in the other type of flight, and that in short it is practically impossible to separate the two when the wings are used actively.

The bird's power of flight is in any case dependent on the efficiency of the wings as planes of the greatest efficiency combined with lightness of weight. A little observation of the wing of the pigeon will illustrate how this has been achieved. The structure of the feathers has been described on page 178, and reference should be made to that description for the device used to produce a surface which is highly resistant to the passage of air through it.

In the pigeon the wing surface is produced largely by 23 large quill feathers. Eleven of these (the **primaries**) are supported by the hand bones and twelve (the **secondaries**) are attached to the ulna in the fore arm. A fold of skin (the **propatagium**) from the shoulder to the forearm and another across the armpit also help, and so do the small covert feathers which overlap at the base of the quill **Wing of pigeon**

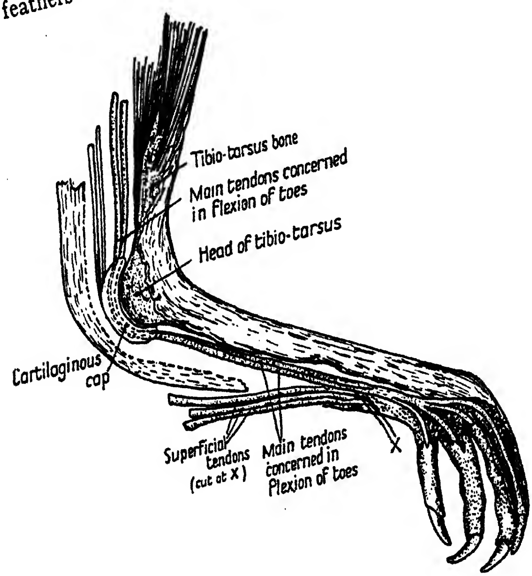


FIG. 120.—Foot of domestic fowl dissected to show perching tendons.

feathers. The motive power comes from great pectoral muscles which are attached to a large keel which is developed on the breastbone of all flying birds. The outer and larger one on each side, the **pectoralis major**, is attached to the under side of the humerus. Its action is direct, and it pulls the wing downwards. It is the largest and most powerful muscle of the body. The **pectoralis minor** lies above this, but although attached practically to the same region, its pull on the wing is very different in direction

(see Fig. 103). Its tendon passes through a foramen at the shoulder joint, which acts as a pulley surface and runs to the upper side of the humerus. The direction of pull is thus changed, and contraction of this muscle raises the wing. The actual position of the feathers in relation to each other is such that when the wing is being depressed the overlapping produces a rigid and resistant continuous surface.

The upward and downward movements of the wings are of different duration—the downward movement being slower than the upward—and the direction of motion is not simply up and down in a vertical plane. Results of close observations show that the long axis of the wing strikes in a plane which is oblique to the horizontal, and the downward movement is from behind and above to a point forward and under. There are other movements involved, and the tail feathers also play a part as well as forming a steering organ.

It is impossible to leave this subject without mentioning the remarkable flights made by certain birds during the seasonal migration from their nesting country to where they spend the rest of the year.

Perching of birds

A most interesting feature, which perhaps can best find a place here, is the perching mechanism of birds. Many birds have to support themselves for long periods on a branch or perch of some kind. They go to sleep in this position. It would be unthinkable for a man to have to hold himself up whilst he slept, and it would be impossible for birds to do so either if it were not for a special mechanism.

If the tendons running down to the toes of a pigeon be dissected out, two main tendons will be found which are concerned in the bending of all four toes. They may be traced from the toes and through little tunnels in a pad of cartilage at the back of the 'heel' joint, and then up to the muscles of which they are the continuation. Contraction of these muscles will of course flex the toes, but the actual bending of the leg at the heel joint which takes place whenever the bird sits, tightens up these tendons mechanically

(see Fig. 120). The weight of the sleeping bird thus tightens up the hold of its toes on the branch.[1]

Walking, Running of Mammals, and Standing of Man

Five different types of movement of the four limbs were recognised by Milne Edwards :—Walking, Running, Crawling, Springing and Scrambling. All involve the support and forward movement of the body on four legs, but details of the type of support and structure of the limbs vary in the different species. The bears move with their soles and palms making contact with the ground. Their movements are slow and clumsy. Wherever speed has been wanted a raising of the wrist and ankle has taken place, and the amount of the foot in contact with the earth has been reduced. Thus in the carnivora only the fingers and toes touch the ground. The extreme is found in the horses, where the animal only touches the ground with the extreme tips of its digits and there is only one toe to each foot. This modification is dealt with elsewhere (page 445). The same type of thing is, however, indicated in man. In walking, the heel touches the ground first and the sole and digits make successive contact with it (except for the instep region). When running, the heel touches the ground less heavily, and in extremely fast sprinting the toe part alone makes contact. The actual movement of the limbs of mammals has been the subject of much observation and photography. Probably the slow-motion cinema camera will enable most complete and reliable analysis to be made in the near future. When a dog walks (and this is characteristic for most four-footed animals) the legs are lifted (if we start with the right fore foot) in the order Right fore foot, Left hind foot, Left fore foot, Right hind foot. A child walking on all fours goes exactly the same way. In more rapid movements the order is changed, as in galloping, but not all species of dog are alike in this respect. The horse and some heavy dogs move in a similar manner in

[1] It is often vaguely stated that in the pigeon and domestic fowl this perching mechanism is effected by a tendon passing in a groove over the knee. This is certainly present, but we find that the mechanism is undoubtedly the tendons referred to above.

the gallop, so that the two fore limbs and then the two hind limbs are off the ground together. The movement of each pair of limbs is not, however, *quite* simultaneous. In this gallop the whole four limbs are only off the ground together for a very brief period. Smaller dogs gallop raising the right and left fore limbs simultaneously, and the lifting of the two hind limbs (also simultaneously) follows very soon indeed after the raising of the fore limbs, so that all four limbs are off the ground for a longer period together.

It is impossible to detail here all the muscle movements which are involved in these movements of the limbs, but in connection with the beautiful co-ordination which is present it may be useful to draw the attention of the reader to the actual muscle control when a man is standing still. Man has developed an upright position, so that only two limbs, the hind limbs, are responsible for the support of the body when standing. At the same time, however, this support is small and the position of man's centre of gravity is high. The result is, the body is not in a state of equilibrium, and mere standing involves the continued and complicated action of a number of muscles and the constant control of the nervous system. Thus a child has actually to learn how to stand and walk. The control becomes later quite automatic, a system of reflexes.

The centre of gravity of the head lies *in front of* the joint with the vertebral column. The head has to be kept erect therefore by neck muscles. If a man loses consciousness, the head falls forwards on the chest. The centre of gravity of the human body lies just in front of the last lumbar vertebra. A line dropped vertically from this in the case of a man standing erect passes a little behind a line joining the hip joints and just in front of a line joining the ankle joints. There is therefore a tendency for the trunk to fall backwards on the thigh joints and the body generally to fall forwards on the ankle joints. The first is prevented (as one may find by trying to bend backwards) by a ligament passing from pelvis to femur. The rest of the balancing on the thigh joints is performed by muscles.

Falling forwards on the ankles is prevented by the action of the muscles of the calf. There is, in addition, however, a big tendency for the weight of the head and trunk to cause a collapse or bending at the knee joints. This is avoided by the controlled action of muscles of the front of the thigh which extend the leg. The angle of the thigh and leg is kept so that the weight of the body is supported by the bones, the muscles just keeping up the balance. All

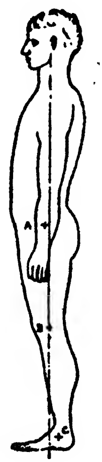


FIG. 121.—Centres of gravity of standing man. (See text.)

this control is involuntary—a complex series of co-ordinated reflex arcs.

Practical work on animal movement

(1) Revise types of movement—ciliary, amoeboid and flagellate—seen in Protozoa.

(2) Observe movements of *Hydra* living in small Aquarium tank. See page 365 for methods of keeping *Hydra*.

(3) Observe ciliary movement in higher animals by (*a*) removing one valve of shell of live mussel or cockle and exposing gills. Allow fine suspension of carmine to fall on gills, and note how the carmine is gradually brought to certain lines of flow. (*b*) Examine a piece of gill under the microscope in a watch glass containing a little fluid from the shell. Note the active ciliary movement. Ciliary

movement may also be demonstrated by rapidly dissecting out the lower jaw, pharynx and oesophagus from a frog just killed by pithing the animal Slit the oesophagus down one side and spread out the tube flat, with the inner surface upwards. Pin down on a piece of cork and rinse surface with Ringer's solution. Small particles of cork should be dropped on the surface of the preparation. They will be carried in the direction mouth → stomach. Note the effect of alterations in temperature on the speed of this movement.

(4) Note ciliary movement causing locomotion in Rotifera—see chapter on pond life. Rotifers are excellent examples of Metazoa moving by ciliary action.

(5) Examine movements of snail's foot by causing a snail to creep over a moistened plate of glass. This permits of observation of the under surface of the foot. Note waves passing from *posterior end to anterior end.* The foot surface is raised from the glass between each wave crest (see Fig. 114).

(6) Note attachments of muscles in abdomen and limbs of lobster or crayfish. Remove with strong scissors the shell from one side of great claw of either example and notice the two muscles for opening and closing the claw. Note attachments to internal skeleton. The closing muscle is the stronger and its attachment surface is correspondingly larger.

(7) Note movements of joints in crayfish and observe different types of movement in living animal—walking, swimming, backward movement.

(8) Examine *Daphnia* and *Cyclops* in small vessel of water and note methods of locomotion. Note effect of directing beam of light on one side of vessel containing these small crustacea.

(9) Examine with hand-lens, wings of beetle, housefly, dragonfly, butterfly and bee. Note the number of wings, place of attachment, and in the case of butterfly and bee note with the microscope the mechanism for holding fore and hind wings of the same side together. (In butterfly by bristle from hind wing projecting into stiff hairs on fore

wing or by a ' shoulder ' on hind wing projecting forward. For bee see page 227).

(10) The movements of an earthworm can be observed by having a large specimen in a dish of clean sand. Note resistance of setae when dead earthworm is passed through fingers.

(11) The swimming organs of a fish should be carefully examined both on living and dead specimens. A goldfish serves excellently for the former, and the action of the different fins should be carefully observed. For simple dissection to make out fin structure, the herring or whiting will serve. The dogfish is somewhat different.

(12) Note locomotion of frog in water and on land. Note position of hind legs before a jump is made. Examine skeleton and determine parts in contact with ground.

(13) After examination of a prepared skeleton of a pigeon make a dissection of the muscles actuating the wings of a freshly killed bird and trace the tendons to their points of attachment. The illustrations should serve as guides. Commence by laying the bird on the back and dissecting out the pectoralis major and pectoralis minor on the sides of the breastbone.

The structure of the feathers should already have been noted (see Chapter X and page 178). Note the arrangement of the feathers. Take a bird's wing which has been preserved dry in an outstretched position. Note that when this is waved up and down in the air the resistance to downward movements is greater than to upward movements. Examine the wing carefully to determine reasons for this. Note also in this respect convexity of wing. The stiffest portion of wing is obviously the front edge again, as in insects, and thus in movements this edge takes up position somewhat similar to that noted for insect wing.

(14) Make dissection of leg of perching bird (pigeon) to show tendons responsible for perching (see page 232 and Fig. 120).

(15) Experiments on muscle may be considered beyond the scope of some zoology laboratories. A few should be seen, if possible. Details can be found in text-books on

physiology. Batteries, coil, electrodes and apparatus for recording muscular contractions are required. This is all somewhat costly to buy, but it is surprising how cheaply anyone with a little mechanical knowledge can put together a makeshift out of the apparatus usually found in a physics laboratory. (See Schafer's *Experimental Physiology* for details.)

XII

THE CELL AND AN INTRODUCTION TO HISTOLOGY

What am I, Life ? A thing of watery salt
Held in cohesion by unresting cells
Which work they know not why, which never halt,
Myself unwitting where their master dwells.
I do not bid them, yet they toil, they spin
A world which uses me as *I* use them.

MASEFIELD.

If thin hand sections of a piece of cork and of a plant stem are cut and examined under the microscope, it will be seen that the sections are built up of a large number of little chambers or compartments with thick or thin walls.

The discovery that the higher plants and animals were both alike in being built up of a number of little units was naturally bound up with the invention and use of the microscope. It was not a sudden discovery, but rather the culmination of a series of researches made by workers during the seventeenth century. One of these which may be mentioned was the discovery that the higher plants were made up of a series of chambers, and Hooke in 1665 made an illustration which was not unlike that which a student would draw after examining the cork section referred to above. Apparently Hooke was the first to speak of these chambers as **Cells**. A long time elapsed, however (during which period many other discoveries were made), before the work of the Germans Schleiden and Schwann (published 1837-1839) initiated our knowledge of the real meaning of these little chambers and revealed also that the microscopic structure of both animals and plants was fundamentally the same. At first attention had been paid to the walls of the chambers, the cavity was thought to be a mere space in the tissue. Thus the term

cell came into being, and it has remained in the literature until to-day, although it is now somewhat misleading unless one is acquainted with the history of its origin. As a result of the work of Schleiden and Schwann it became known that the *contents* of the little plant cells were really the essential units of which the plant was built, and attention was thus focussed upon the living substance we call protoplasm. We have already learned something of this in our investigation of the single-celled Protozoa. As a matter of fact, cell-walls are not nearly so conspicuous in animals, nor are they so resistant to decay. In plants, on the other hand, the cell-walls often remain long after the living substance of the cell has disappeared; in fact, a piece of wooden furniture hundreds of years old consists only of cell-walls. Let it be kept in mind, therefore, that in

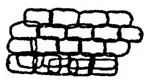


FIG. 122.—Hand section through piece of bottle cork.

regard to the structure of living things, the term 'cell' is a misnomer, and that when we use it we mean a little mass of protoplasm enclosing a nucleus.[1] Out of these units the bodies of both the higher plants and animals—those known as multicellular organisms—are built, and every cell which comes into existence arises from a pre-existing cell.

In a later chapter on reproduction it will be shown that the multicellular animals arise either from a small group of cells cut off from the parent, or else, and this is by far the most usual, from single cells which are known as **Germ Cells**. However, the units which go to make up a building are very diverse—there are bricks, blocks of stone, planks, iron girders, electric light wires and so on. The same diversity is found in the multicellular animal body. From

[1] A somewhat similar kind of misnomer is quite familiar to all who are acquainted with electric batteries. We speak of them as built up of cells. Each cell is a container, but the essential parts are the contents, the chemicals, etc.

a beginning as a single cell or a small group of cells there are first produced stages in which all the cells are very much the same in appearance, and then, as development continues, the cells become specialised, adapted for very different functions. Corresponding to this they vary considerably in structure. There are exceedingly long muscle cells, nerve cells with a long process which may even attain a length of several feet, large egg cells with stores of yolk, gland cells and so on. The smallest cells are found amidst the bacteria, and probably some of these are too small to be seen with the highest powers of the microscope. The largest of all cells are those eggs which contain abundant stores of yolk, that is, the eggs of birds and sharks. Thus

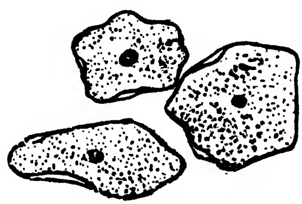


FIG. 123.—Cells from inside of cheek. × 550.

the largest egg cell of a living organism is that of the ostrich. (Only the part familiarly known as the yolk is the real egg cell. The white of egg and shell are accessory structures.) But notwithstanding the diversity, there is a fundamental resemblance between all cells, and thus we can describe the more or less common features and speak of a typical cell.

(1) Scrape the inside of the cheek gently with the *handle* of a scalpel and examine a little of the scraping in saliva under the microscope. Note the cells and observe the nuclei (Fig. 123). **Practical Work (I)**

(2) Place a drop of blood from a frog on a glass microscope slide and make a preparation by following the instructions given on page 463.

(3) Examine *stained* sections of the tip of hyacinth or onion roots. (If a microtome is available, bulbs should be grown over water and the growing tips of the rootlets

sectioned and stained (see page 464); otherwise a good preparation should be purchased.)

In most cases examination of the living animal cell reveals only a mass of colourless protoplasm containing a nucleus; unless there be obvious granules or droplets of waste products in the protoplasm, or spaces—vacuoles (as seen already in the Protozoa). In the green plant cell, as in green *Euglena*, other little bodies containing the green chlorophyll may also be seen—chloroplastids. The nucleus of the cell has a marked affinity for certain dyestuffs, and it was realised at an early date that by killing the cell and

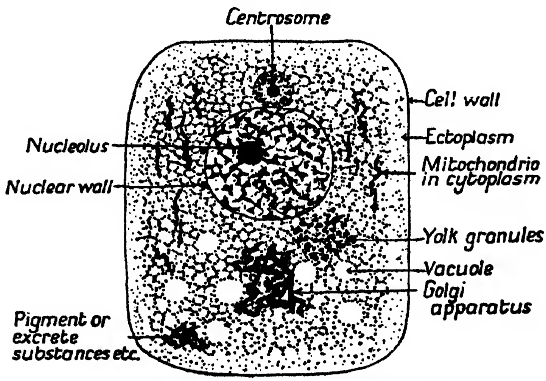


FIG. 124.—Diagram of a generalised cell.

staining it, it was possible to differentiate structures which could not usually be seen in living cells. Simple staining and the use of low powers of the microscope do not generally bring out very much more than the nucleus and the other features referred to above, and this corresponds to an actual stage in the history of cell investigation. In our preparations of the cells from the cheek, and the blood corpuscles (typical cells) from the frog (Fig. 74), there is probably nothing more to be seen than a little mass of protoplasm enclosing a nucleus. The protoplasm which surrounds the nucleus is often termed **Cytoplasm** to distinguish it from the protoplasm of the nucleus (**Nucleoplasm**). We shall use these terms in the following description, for there is a very definite difference in the chemical

composition and the functions of these two parts of the cell. The chemical difference is already indicated by their difference in the reaction to dyestuffs.

Much more elaborate technique and higher powers of the microscope have gradually led to the discovery of other structures in the cell, and the illustration (Fig. 124) shows the various features which may be found in a *resting cell*—that is to say, one which is not undergoing division or just about to divide. It is not suggested that all may be seen in one and the same cell, for in order to see the structures depicted in the illustration it is necessary to treat a cell with many different reagents. Moreover the cell must be killed without any serious change in structure. Many mixtures have been invented for this purpose. These mixtures must also have the effect of preserving the cell structure so that it will stand the after-treatment with dyes, etc. It is almost like a well-known photographic method slightly altered in order of processes. There is nothing visible on an exposed film. We immerse it in developer and gradually a picture unfolds itself. We then 'fix' the film so that the picture does not disappear. In the case of the cell we render the structures permanent, first with a mixture called a 'Fixative' and then we 'develop' them with stains. Now it will be noted that what we usually study is a dead cell, after treatment with many chemicals. Possibly some of the things we see may not have existed at all in the living cell (which is a mass of semi-fluid substance). On the other hand, careful comparison of the results of different methods of treatment checked at times with observations made on living cells which happen to allow of certain structures being very favourably seen, enable us to be more certain of what is natural and what artificial. (See end of book for microscope technique.)

The "resting" cell

Usually animal cells do not possess a thick **Cell-wall**; there may be a delicate membrane or there may be apparently no cell-wall at all, but usually the most external cytoplasm is slightly modified. The actual structure and composition of the living protoplasm is naturally of tremendous interest, for one might say that the solution to

all the fundamental riddles of life is locked up in this substance. It is a difficult subject, however, and we must pass over it here.

The nucleus

The **Nucleus** is bounded by another delicate membrane, the **Nuclear Wall.** It is therefore almost like a little sac suspended in the cell and usually regular in shape. The nucleus is of profound importance to the life of the cell, and without it a cell is unable to perform its normal functions of nutrition, growth and reproduction. (It has been possible with the aid of delicate apparatus to remove the nucleus from a cell, and even to cut living cells into two parts, one containing the nucleus and one without. The former may regenerate the lost part, the latter soon dies.) Thus the nucleus is regarded as the controlling centre of the life of the cell. Probably active exchanges of material take place between its contents and the cytoplasm surrounding it. We may anticipate matters by stating that the appearance of the nucleus is very different when a cell is dividing from that of the resting, growing, stage. We shall describe the dividing cell later. Within the nucleus on a ground substance or framework there is a network of granules of another constituent known as **Chromatin.** It is this material which causes the nucleus to stand out so distinctly in most stained preparations, because it has a strong affinity for certain stains. Experiment has shown that this Chromatin is of the greatest importance in relation to heredity.

One or more small spherical bodies with different staining properties may often be found inside the nucleus. They are still imperfectly understood. One of more definite type, the **Nucleolus,** stains differently from chromatin and frequently disappears when a cell divides. Its function is still unknown.

Just outside the nucleus and within the cytoplasm is a region of modified cytoplasm which may enclose one or two minute bodies known as **Centrosomes.**[1] These play an obvious part when the cell divides, but in all probability they also have other functions. It is not always possible to find the

[1] Sometimes these granules are known as Centrioles.

centrosome in cells which are not in a state of division. These are not found at any time in the cells of higher plants, but are characteristic of animal cells and those of the lower plants.

Of recent years still other structures have been discovered within the cytoplasm—the **Mitochondria** and the **Golgi Body.** These structures require special treatment for their demonstration.

Mitochondria may have the form of delicate short filaments or may be granular. Their function is still problematical, although they appear to be concerned with the formation of a variety of materials (pigments, secretions, fibrillar structures in the cells, etc.).

The Golgi body, called after an Italian scientist, Golgi, who was the first to describe it, is really a modified part of the cytoplasm in the form of a number of rods, little strands or a network. It is not easily made clear unless experience in cell study has been attained. It is apparently concerned in the secretory activities of the cell and may enlarge at such times as a cell is actively secreting.

The dividing cell

The most remarkable indication of hidden complexities in the cell is furnished when cells divide, and since all cells originate from previously existing cells this process, which is the culmination of cell growth, is of deep interest. It was not until after 1873 that the steps in this process came to be discovered, yet it is not difficult to see them, and the characteristic stages should be quite obvious in a section through the onion or hyacinth root tip. (Note again the fundamental resemblance between animal and plant structure.) In comparatively rare cases cell division consists, first of a lengthening of the nucleus, which becomes dumb-bell shaped and then constricts into two halves, and this is followed by the division of the cytoplasm. This is known as **Direct Division.** In most cases division is a much more interesting process, during which the cell divulges some of its secrets. This type of division is **Indirect**, and the term **Mitosis**, or **Mitotic Division**, is generally used to denote it. The various stages are explained by the figures. First, as the cell nears the time for Mitosis, the chromatin begins to increase in staining power, and

Mitosis

instead of existing as a network of granules in the nucleus, it condenses or collects up into coiled and tangled threads. These threads contract lengthwise and so become thicker. They stain more intensely. In the meantime outside the nucleus the two centrosomes (if the centrosome were single in the growth stage, it will have divided to give two) move gradually apart, still keeping close to the nucleus, and between them a **Spindle** of connecting fibres appears, whilst other fibres radiate from them into the cytoplasm.

The nuclear wall now disappears, and the threads of chromatin have become very conspicuous rod-like structures which are known as **Chromosomes.** This is perhaps the most interesting feature of Mitosis. The Chromosomes are very important bodies, and they have played a very big part in biological discovery of the last ten years. We shall return to this again below.

The chromosomes arrange themselves about what we may term the equator of the nucleus. In the meantime the spindle from the centrosomes has invaded and crossed the nucleus, one centrosome being at each pole. Each chromosome now appears to be split lengthwise into two exactly similar halves, and these halves begin to diverge to the opposite poles. It would almost appear as if they were pulled by the fibres which extend to them from the spindle poles. The final result is that a number of daughter chromosomes, equal to the original number of whole chromosomes, collects at each end near a centrosome. Following this, the first steps described are, so to speak, traversed backwards; the daughter chromosomes form a tangled skein, this becomes a mere network of granules and a nuclear membrane appears. Thus we have two nuclei reconstructed in one cell. The cytoplasm now begins to show indications of a partition between the nuclei, and eventually division takes place and two cells result. (The various steps, with the names given to them, are indicated in Fig. 125.)

Chromosome numbers

We must now return to the chromosomes. The number of these in a cell is a matter of importance, for it has been found that with certain exceptions, it is constant for every

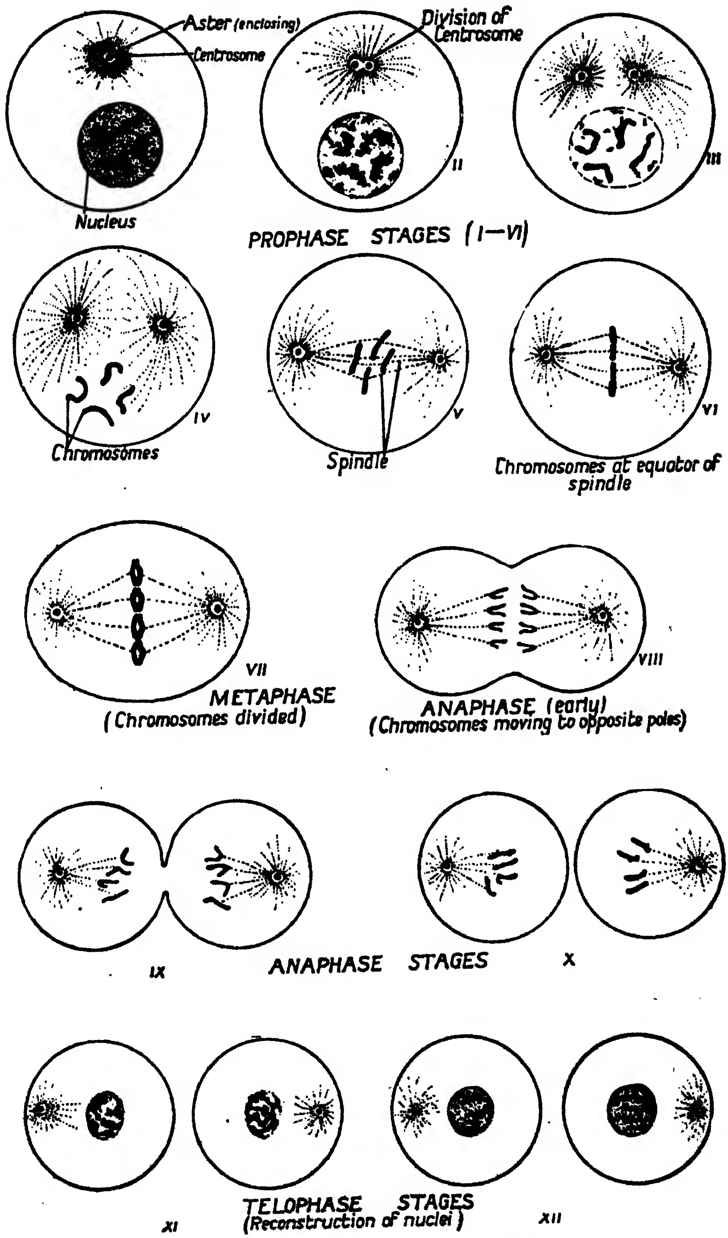


FIG. 125.—Diagram of mitotic cell division.

cell of the same animal and also in all other animals of the same species. But each species has its own characteristic number. In man this is 48, in the lily 24, the hyacinth 16, the cat 35 or 36, a red ant 48 and so on. Most animals have a number between 12 and 50, and so it will be noticed that, whilst there is a number which is characteristic for every species, this number is not different for every species, and two very different animals or plants may have the same chromosome number in the cells. The important thing, then, is not the actual number, but the constancy of the number in the cells of the individual. The mature

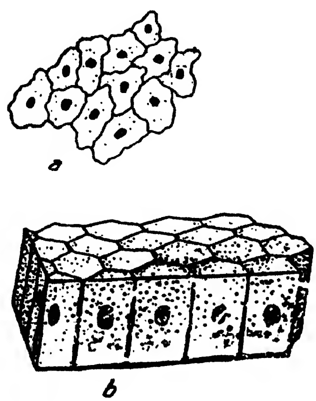


FIG. 126.—(*a*) Squamous epithelium. (*b*) Columnar epithelium.

cells of the organs of reproduction form an exception to this rule. Mature egg cells produced by the female and spermatozoa (formed by the male, see Chapter XVI) have only half the chromosome number characteristic of the cells of the body. We shall see later how this can be explained.

DIFFERENTIATED CELLS. TISSUES, ETC.

In the Metazoa the cells form tissues of which the different organs of the body are constructed. A tissue is, properly speaking, a collection of cells specialised to the same end and performing, as a rule, one particular function. The collection of cells may form a sheet, one cell thick or

several layers in thickness; the cells may form tubes, and an organ may consist of almost nothing else but such tubes. Finally, one may find cells aggregated together to form irregular masses. Sometimes the cells in a tissue touch each other on all sides. In other cases they become more or less separated by substances produced by their activity. In many cases it can be seen that adjoining cells are actually directly connected with each other by little bridges of protoplasm (see Fig. 1).

A very brief résumé of the specialisations met with amongst the body cells is given under the heads of the

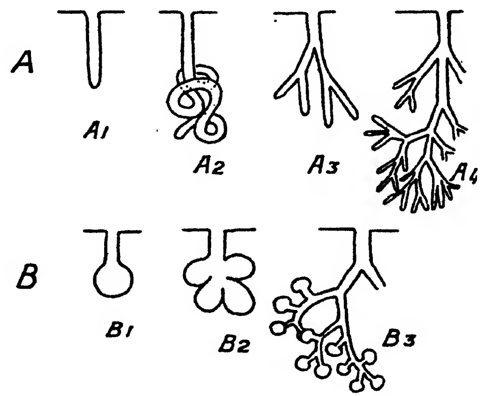


FIG. 127.—Diagram showing how glands are formed by infolding of an epithelial layer.
A. Tubular glands. *B*. Alveolar glands.
A_1, A_2 and B_1 are simple glands. A_3, A_4, B_2 and B_3 are compound glands.

following tissues:—**Epithelial Tissues, Connective Tissues** including **Cartilage** and **Bone, Muscle, Nervous Tissues,** the **Blood,** the **Germ Cells.**

1. *Epithelial Tissues.*

These tissues are usually sheets of cells which form membranes and bound external surfaces of the body, or line internal cavities (Fig. 126). The cells are not unlike the typical cell described, for in most cases there is but little specialisation. They touch each other, and there is only a small amount of substance between them, if any. Sometimes, in addition to merely bounding surfaces, the

cells of an epithelium may be modified for the reception of stimuli or for secretion or excretion Thus, glands may be formed from a glandular epithelium, and all stages may be met with from a mere glandular surface, or a simple tube like ingrowth, to a complicated gland of branching tubes or little chambers (see Fig. 127). Some glands consist of massed epithelial cells and no duct may be present (the Thyroid gland is ductless).

Practical work (II) I. The cells examined above from the cheek are epithelial cells. In this case they are flat scale-like cells, and so the epithelium is known as Pavement or **Squamous Epithelium.**

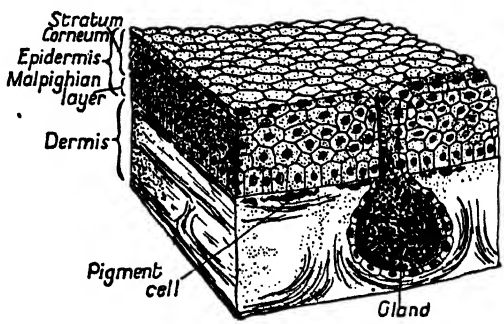


FIG. 128.—Skin of frog.

II. Examine sections through the stomach of the frog for a glandular epithelium thrown into folds.

An epithelial tissue rests always on a support of connective tissue to which it may be closely cemented.

An epithelium may consist of several layers of cells. It is then called a **Stratified Epithelium.** This may also be called squamous or cubical or columnar according to the character of the outermost layer of cells.

III. Examine a section through the skin of the frog for an example of stratified epithelium (Fig. 128). Note also the spherical chambers (glands) communicating with the surface by a short tube.

IV. Examine a little piece of gill from a live mussel or oyster, keeping it wet with some of the fluid from within the shell. In this case notice the well developed cilia (see Chapter VI) which are borne by the cell and serve to

set up currents in the water in contact with the cells. They may be seen better if slowed down by adding thick solution of gum arabic in sea water. An epithelium made up of ciliated cells is known as a **Ciliated Epithelium.** (See also page 121.)

2. *Connective Tissues.*

These are tissues in which the cells are more specialised and in which a large amount of intercellular substance is developed, so that the cells lie separated by a matrix. In

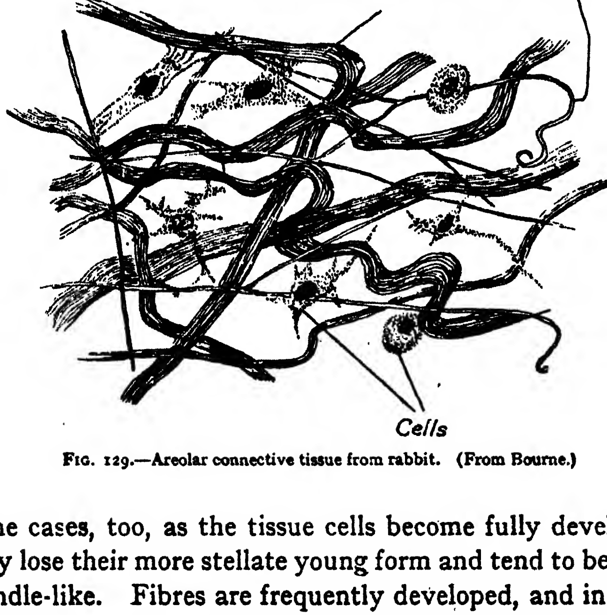


FIG. 129.—Areolar connective tissue from rabbit. (From Bourne.)

some cases, too, as the tissue cells become fully developed they lose their more stellate young form and tend to become spindle-like. Fibres are frequently developed, and in bone the matrix becomes strengthened by the deposit of lime salts. Such tissues serve for support and protection and also for the attachment of muscles.

(a) Areolar, elastic and fibrous tissues; fatty tissue

These tissues (Figs. 129 and 130) are all varieties of a fibrous connective tissue. In **Areolar Tissue**, which is perhaps the most common type, the ground substance is delicate and not easily seen. Delicate fibres of two kinds are entangled together with the cells. Some run in bundles, others singly. Those which always run in bundles, take a wavy course and, whilst branching, do not join again, are

known as *White Fibres.* The others, fewer in number, both branch and join and thus form a network; they are called *Yellow* or *Elastic Fibres.* This kind of tissue fills up spaces between one kind of tissue and another. It lies between the epithelium of the skin and the underlying structures.

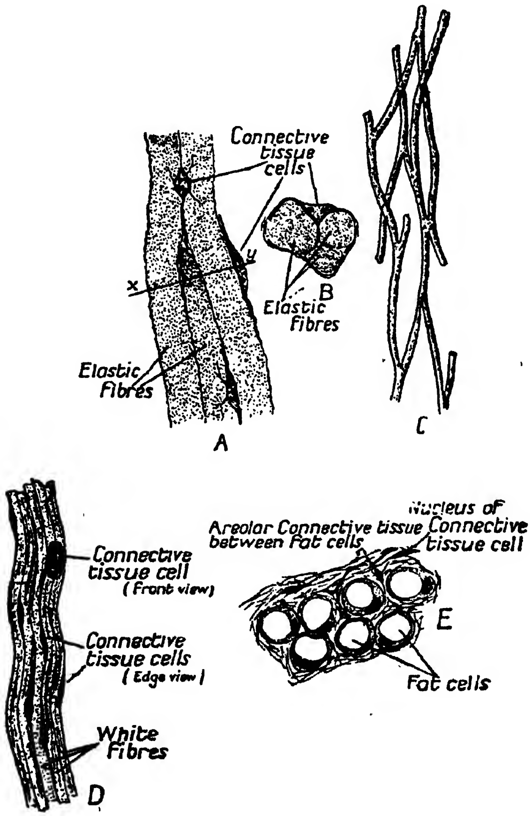


FIG. 130.
A. Longitudinal section of ligamentum nuchae of ox.
B. Transverse section of *A*.
C. Elastic fibres of the ligament alone and slightly separated.
D. Fragment of tendon. Highly magnified.
E. Adipose tissue. Highly magnified. (Modified after Dahlgren and Schafer.)

Dense Fibrous Tissue is made up of groups of white fibres running together and forming large bundles. In between the bundles are rows of cells. This tissue forms the tendons of muscles and also membranes where great strength is required. (Fig. 130, *D.*)

Elastic Tissue is one in which the yellow elastic fibres prevail almost entirely, and there is little ground substance. An excellent example is the ligament which supports the neck in the cow, horse, etc. (Fig. 130, *A*, *B* and *C*.)

Fatty or **Adipose Tissue** is a connective tissue with few fibres and with the cells swollen by the presence of fatty matter. It may be looked upon as a variety of areolar tissue. (Fig. 130, *E*.)

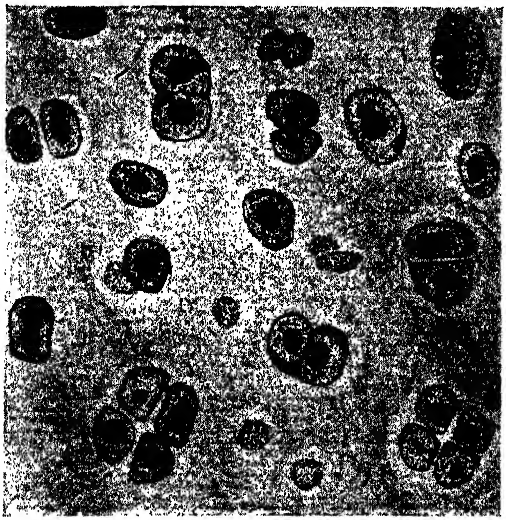


FIG. 131.—Hyaline cartilage from sternum of frog. Magnified.

(1) *Areolar tissue* can be obtained by taking a little of the loose subcutaneous fibrous tissue from the rabbit. Spread it out on a dry slide, using needles. It will stick to the slide. Do not let the central part which is to be examined dry up. Keep it moist by breathing on it. Place a drop of salt solution on it and apply a cover glass. The preparation may be stained (see page 461) instead of adding salt solution, and permanently mounted or examined in glycerine. **Practical work (III)**

(2) *Tendons* can be obtained most easily from the tail of a dead rat or mouse. All that is necessary is to pull off the end of the tail and pull out the obvious tendons. Spread one out in a drop of salt solution and examine under

a cover slip with low and high powers. Tease it a little if necessary. Add a drop or two of acetic acid, and note how the fibres swell up and become transparent. The tendon cells will become visible in longitudinal rows between the tendon bundles. The acid can be washed away and the preparation stained (see page 461).

(3) A shred of the **Ligamentum Nuchae** from an ox should be teased out with needles in salt solution or glycerine and water. (Fig. 130, *A*.)

(*b*) Cartilage

Cartilage is a firm elastic tissue in which there is an abundant matrix formed by the cells and in which they lie. This tissue is often found in connection with the skeleton of the vertebrates, and it also forms the skeleton in the earlier stages. It is not often found in invertebrate animals.

Two types of cartilage may be noted :—**Hyaline Cartilage,** in which the matrix is free from fibres, and **Fibrous Cartilage,** in which obvious fibres are present in the matrix.

Hyaline cartilage forms the anterior and posterior ends of the sternum (breast bone) of the frog. It covers the ends of bones at joints, and in the higher vertebrates it is present on the ribs, in the nose and outer ear, and in the larynx.

Cartilages are covered on the outside by a fibrous membrane called the **Perichondrium.** It is by way of this that the cartilage receives a blood supply.

Practical work (IV)

I. Examine in salt solution under the microscope a piece of the upper or lower end of the frog's sternum, cleared of connective tissue and muscle. Note the cells in capsules. Often they lie in packets of two or four, indicating that they have been formed by division and the matrix has not yet been produced round them in such quantity as to separate them to any extent.

II. Examine a prepared microtome section through a tadpole's head and note that the skeleton is of cartilage.

(*c*) Bone

Bone is a very firm connective tissue in which the cells are separated by a matrix formed by them and which has been made hard by deposition of salts of lime (calcium phosphate chiefly). It is found in the skeletal system of vertebrates. The hard skeleton of some sharks is like this,

however, and yet is not bone. It is necessary therefore to add that the matrix of bone is laid down in a special manner, and that there is a characteristic structure which distinguishes bone from those types of cartilage which have been impregnated with lime salts. True bone is not found at all in the invertebrates, nor in the lower vertebrates. It occurs from the bony fishes upwards.

III. Take two similar long bones from the limbs of sheep, cat or dog, etc., and place one in dilute hydrochloric acid for about a week. Place the other on a plate **Practical work (V)**

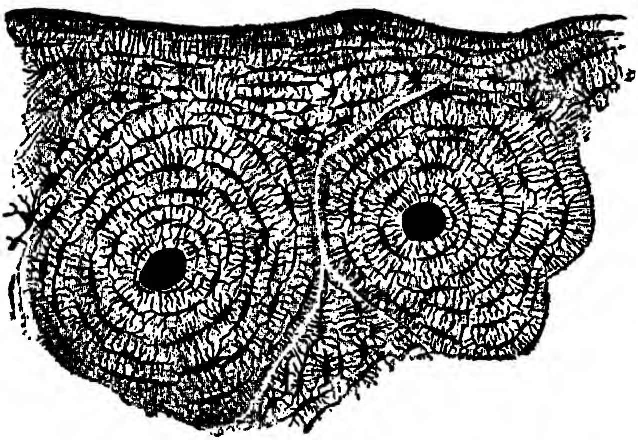


FIG. 132.—Transverse section through small piece of bone, showing two Haversian systems. (From Bourne.)

and heat it to redness over a Bunsen burner. The bone which has been heated will have lost all its animal matter (lost about one third of its weight). Note how brittle it is. The bone treated with acid will have lost the lime salts, and the organic matrix only will be left. Note its flexibility.

Examine sections of a long bone—made with a saw and taken in two directions, transverse and longitudinal. (Bone may be compact or with a large number of spaces—cancellated bone.) The outer layers of the long bone are compact, and probably only a little of the part immediately bounding the marrow cavity of the bone is cancellated. Examine microscope sections of compact bone mounted dry. Notice in the transverse section (Fig. 132) that the

bone is made up of more or less concentric layers, the **Lamellae,** which consists of calcified matrix with fibres. In the little spaces, the **Lacunae,** were formerly the bone cells (bone corpuscles). These were much branched, and this is indicated by the little canals, **Canaliculi,** which run out in all directions from the lacunae and unite them. (These lacunae and canaliculi show up black in dry mounted sections, Fig. 132.) The lamellae surround passages known as **Haversian Canals,** which run in the direction of the long axis of the bone and have cross branches here and there. Blood vessels and nerve fibres run through these canals during life. An Haversian canal with its surrounding lamellae, bone cells, etc., is known as an **Haversian System.** In cancellated bone there are no Haversian systems, and the blood vessels just run in the irregular spaces which contain marrow.[1]

The outside of the bone is covered by a sheath, the **Periosteum,** containing the larger blood vessels which communicate with the capillaries of the Haversian systems and the marrow. Thus, in life the whole of the bone, including the imprisoned bone cells and the marrow of the internal cavity, if there is one, is constantly supplied with blood. The periosteum plays a big part in the growth of bone and the repair of breakages.

Bone is formed either by the *ossification* of cartilage or of connective tissue—both processes of formation are common (Cartilage bones and Membrane bones).

3. *Muscle.*

Muscle is composed of more highly specialised cells in which a delicate fibrillar structure is usually developed and in which the protoplasm has developed the general vital property of contractility to a marked extent. It is one of the earliest tissues to be developed in the animal kingdom.

[1] In the cavity of long bones there is a substance—bone marrow—which is rich in fat cells and richly supplied with blood vessels. This tissue is actually a source of cells which build bone (osteoblasts), others which destroy bone (osteoclasts) and of blood corpuscles. In fact, in adult life the bone marrow is probably the only source of new blood corpuscles.

The contractility is almost always limited to one direction in a muscle cell, and this is in accordance with the differentiation of the contractile fibrils—**Myofibrils.** The protoplasm of the cells is often known as sarcoplasm. Further details of muscle cells are given on page 209 in connection with muscular tissue and animal movement.

4. *Nervous Tissue.*

The manner in which cells become specialised and build up the nervous system of the multicellular animal is

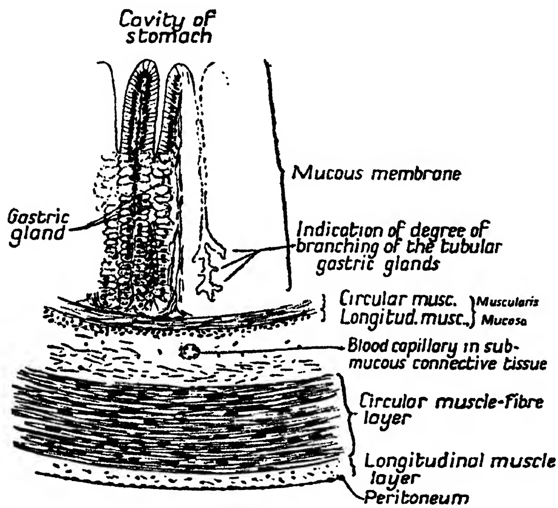


FIG. 133.—Portion of transverse section through stomach of frog.

described in connection with the nervous system (Chapter XIII) and the sense organs.

5. *Blood.*

The blood is also to be recognised as a tissue although it is a fluid. It may be regarded as a tissue where the intercellular material is fluid, for it consists of a liquid, the ***plasma,*** in which float living cells, the blood corpuscles. Since a special chapter has been written on the blood, reference to its structure has been transferred to that section (see Figs. 74 and 75).

6. Germ Cells.

The nature of the cells which are produced by the two sexes of multicellular animals for purposes of reproduction is described in connection with the phenomena of animal reproduction (see Chapter XVI).

In this short account we have shown how one undifferentiated cell gives rise by division to a large number of cells which become different organs of the body, and which, as they develop, specialise along certain lines, keeping and in some cases enormously developing certain features of the typical cell, but at the same time losing other characters.

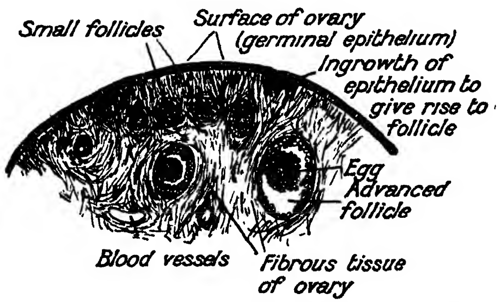


FIG. 134.—Portion of section through ovary of a mammal.

We have studied the structure of the typical cell in detail in this chapter. We might say its vital characteristics were those of an Amoeba or a white blood corpuscle. The muscle cell has specially developed one character of such a typical cell—the power of contractility. The nerve cell has developed the power of conduction, and so on. But in the adult multicellular animal in most cases this specialisation means a great loss of the power of reproduction (and ultimately the power of cell division is lost). The germ cells alone seem to have kept themselves free from the specialisation, and free from the activities of the living animal, which culminate in senile decay and death. They are produced in special organs termed reproductive organs or gonads.

How tissues build up

It must be realised that we have given the merest outline of some of the different tissues which make up the organs

found in the body. These organs are composite structures, and often of very complex build. Certain of them (the kidneys, for example) are referred to elsewhere in this book. An excellent example showing how an organ is built up of tissues may be seen by examining a stained microscope preparation of a transverse section through the frog's stomach.

On the inner face we have a **Mucous Membrane,** which is a folded epithelium containing numerous gland cells. These again are of different kinds, and those which line the tubular downgrowths secrete digestive juices ; each downgrowth or tubule is a gastric gland. Below this epithelial part is a layer of areolar connective tissue which carries blood vessels, and also serves to connect the epithelium with an underlying layer of muscle fibres. This muscular layer is itself divisible, for the muscle fibres run in different directions (see Fig. 133). Finally, on the outside the stomach is bounded by another and delicate epithelial layer, part of the **Peritoneum,** the layer which bounds the body cavity.

Again, an ovary of a mammal is a small, almost solid, organ consisting very largely of fibrous connective tissue and bounded on the outside by the all-important epithelium which gives rise to the germ cells—the eggs. But the eggs are not formed on the surface. The outside epithelium sends downgrowths into the fibrous tissue of the ovary, and these become cut off and form little nests of cells (**Graafian Follicles**), in each of which one cell becomes an egg cell. In addition to these parts there are scattered muscle fibres running here and there, blood vessels to supply nutriment and oxygen, nerve fibres and some special epithelial-like cells called **Interstitial Cells.** Thus this whole structure forms a complete unit with its own special functions.

XIII

THE HARMONIOUS WORKING OF THE ORGANS OF THE ANIMAL BODY

PART I. CHEMICAL REGULATION

THE single-celled *Amoeba* or *Paramecium* might almost be compared, for the purposes of this chapter, with a one-man workshop. The cell is in direct contact with the environment and this direct contact supplies us with a relatively simple example of function control in a living creature. The relation of food supply, excretion, and oxidation, to movement and to all the phenomena of life in the cell, is reduced to the activities of the one little mass of protoplasm—although this apparent simplicity must not disguise the fact that the whole living mechanism even here is exceedingly complex and still a problem.

When, however, we come to the larger and multicellular organisms with specialised parts, a much more elaborate system is essential. The heart must beat at such speed as will supply the rest of the body with just the right amount of oxygen and food. The respiratory mechanism must work in accordance with the demands of the living protoplasm for oxygen—demands which vary all the time because of the varying activity, varying consumption of food, varying environments, etc.

The different stimuli accepted by sense organs—sound, light, touch, etc., must all be correlated at some centre or centres, and the responses sent to such different parts of the body as is proper. A frog is no more a mere collection of organs—brain, stomach, kidneys, etc.—than is a human being, and if there were no co-ordination between these different parts the life of the whole would cease to exist in a few minutes. You can imagine what would happen in, say, a huge soap factory, if four times as much alkali as was required were accepted by those taking in the raw materials, or the men at the mixing vats mixed the wrong proportions, or the girls in one of the packing rooms suddenly refused duty without saying anything about it to other departments, or the boilers were not fed with

water. But all this is as nothing compared with the amazingly delicate interaction of the organs in a human being.

A runner is awaiting the starting shot at the Olympic Games—his eyes take in the huge crowds, he realises more than ever the significance of his task, his whole body reacts, his pulse beats slightly faster, then comes the start, his ears receive the signal, this results in the most active movements of a whole set of muscles, energy is used and more and yet more, the muscles cry out for oxygen, the heart responds to the call, the beat quickens and simultaneously the respiration quickens to supply oxygen to and remove carbon dioxide from the ever faster running blood stream. There are changes taking place all over the body, blood vessels dilate or contract, the spleen and other organs give up stores of blood, the function of the blood vessels of the digestive organs may be almost temporarily suspended.

How are all these changes in activity kept in step and set going exactly when required? And this is only one example. All the activities of the body are interwoven, all the different organs are interdependent.

Probably in all the multicellular animals this harmonious functioning is achieved by two methods. 1. A nervous mechanism, long known, and consisting of special centres (brain and other collections of nerve cells) with nerve fibres like telegraph wires from one part to another. 2. A chemical system by which chemical substances liberated by one part are conveyed by the blood to another organ which they stimulate to work harder or they slow down. It is only recently that the amazing extent of the activities of this second system has been realised. To-day the new knowledge is revolutionising medicine.

The chemical regulation of the body is chiefly concerned in the control of slow processes like digestion and metabolism generally, of reproduction and the still slower process of growth. Nerve reactions are quick. But some chemical regulation is by no means slow. One of the best examples is the stimulation of the pancreas to secrete its digestive juices at the correct moment (see page 65). Thus the semi-digested food passing into the intestine causes certain glands in the intestine wall to produce the substance—Secretin. This is poured into the blood which carries it to the pancreas, where it acts as a messenger-stimulator and causes the pancreas to perform certain work. The response, if not in a fraction of a second like a nerve reaction, takes only a few seconds.

It was the discovery of the part played by Secretin which resulted in the name **Hormone** being given to such chemical substances which are liberated by one part of the body and carried in the blood as regulators. But the name Hormone suggests that all these chemical regulations act by *stimulating* some part to action, and this is not true. As time went on, more and more reactions in the body were found to be controlled by the secretion of special chemical substances, the most impressive being the effects produced by special glandular organs in the vertebrates, organs whose functions had for centuries been problematical. These glands were called Ductless Glands, because instead of the secretion passing out by a duct as the pancreatic digestive juices from the pancreas, it passed directly into the blood. Unfortunately this is also a bad term, because some glands *with* ducts also produce the other kind of secretions too. Nowadays the term **Endocrine Glands** is used for the glands and their special secretions are *endocrine secretions.*

The most important Endocrine glands are the *Thyroid,* the *Adrenal Glands,* the *Pituitary,* the *Parathyroids,* the *Reproductive Organs,* the *Pancreas,* and the *Intestine.* Some of these produce several different endocrine principles, the Pituitary producing at least ten, and the reproductive organs several (this is altogether in addition to the function of the latter in producing eggs or spermatozoa).

The Thyroid secretions control Growth. Defective thyroids in babies cause Cretinism—the child remains undeveloped, a stunted dwarf of imbecilic appearance. One of the most surprising and efficient discoveries in Medicine is that many such cases can be completely brought to normal by administering doses of Thyroid extract. Incidentally the products of these endocrine glands appear to be the same in different animal species, so that the Thyroids and Pituitaries of sheep are used for the manufacture of the endocrine principles for treatment. The production of too much secretion is of course as bad as a deficiency—normal regulation and harmony require normal secretion.

The growth of dwarfs as well as of giants amongst human beings (the 'circus' personalities) is often due to abnormal activity of the pituitary.

This co-ordination of the working of different parts of the body by chemical messengers is too big a subject to follow here—and too new. One or two further examples must suffice.

It is well known that frogs, and certain fishes (as well as some

reptiles and invertebrates) change colour according to the degree of illumination or colour of their surroundings. In some cases this is effected by way of the nervous system acting on colour cells in the skin. In the frogs, however, the light or dark conditions of the surroundings, reacting through the eyes and skin, cause the pituitary gland to reduce production or to produce more of a secretion which, carried by the blood, influences the colour cells in the skin, making them contract or expand. Probably the same sort of mechanism is involved in changes of colour in fishes.

Another striking activity which may be mentioned is consequent upon one of the secretions from the Adrenal Gland—Adrenine, produced by the central part, the medulla. The adrenal medulla is evidently very susceptible, by way of the nervous system, to emotional disturbances caused by pain or excitement associated with combat or dangers of the environment. As a result of excitement an increased discharge of adrenine takes place into the blood stream. Blood vessels are constricted, there is increased activity of the heart, a general heightening of tone in the central nervous system and the muscles, and some action on the change of glycogen to sugar. As one author puts it: 'The organism which, with the co-operation of increased adrenal secretion, can best muster its energy, can best call forth sugar to supply the labouring muscles, can best lessen fatigue, and can best send blood to the parts essential in the run or the fight for life, is most likely to survive.'

The whole matter of the Endocrine Glands is more complicated still because there is an inter-relationship between them. This is one of the newest fields of discovery. Suffice it to say that there is clear evidence for a very delicate balance between the working of the different parts of the body, and that in vertebrates the Endocrine system plays a striking part in what may be termed multiple control.

XIII (*Cont.*)

PART II NERVOUS SYSTEM AND SENSE ORGANS

FROM the preceding chapters, especially from those on Muscular Activity and Locomotion (Chapter XI) and the Endocrine Organs, something of the remarkable co-ordination existing between the different organs of the animal body will have been realised. We have just dealt with what may be called a chemical system by which messages can be sent from one part of the body to another. We now turn to a more familiar system, the Nervous System, which subserves the highest functions and which presents a remarkable range of development in the different animal classes from the Coelenterates to Man.

The activity of a great pianist at the piano, of the artist painting a picture, or of the ballet dancer in the theatre is all a matter of the contraction and relaxation of muscle fibres. Each muscular contraction is the result of an impulse received from a nerve fibre. Out of a multitude of these responses a beautiful and co-ordinated action results.

An eel which has had its head chopped off will go on wriggling actively for a little time, and a lizard's tail which has been dropped off by the animal in its haste to get away from danger often moves more actively than the lizard itself. A German scientist (Goldschmidt) tells a tale about a Japanese employed in an eel preserving factory who was able with one sharp cut to divide an eel into two and remove the backbone and spinal cord. The mass of muscle, without attached head or spinal cord, showed none of the active wriggles mentioned above; the central muscle control had been removed.

The central nervous system is responsible, not only for the conduction of impulses to the muscle fibres and to glands, but also for the co-ordination of these impulses. But

it performs more than this. The movements of a tennis player, for example, are co-ordinated in relation to something which takes place outside him—the approach of a tennis ball, for instance. The movements of a pianist may be similarly related to some printed notes on a sheet of paper as well as to the black and white keys he touches. These stimuli from the environment are received by the sense organs and handed on to the nervous system, which analyses and controls the responses. In the higher animals, in man, it is part of the nervous system which is the seat of mental activity.

The brain is our centre of conscious life. Many people believe that they distinguish touch sensations by the part of the skin, say the tip of the finger, which is in contact with the object touched. The pain caused by a pin-prick is certainly felt at the point where the pin entered, but, as a matter of fact, the central nervous system is responsible for the conscious nature of this sensation, and experiments have shown that if the nerve or nerves affected by the prick were to be stimulated some distance inwards from the skin (the nerve being cut), the pain would still be felt as if at the skin surface. Similarly an injury to part of the brain might result in blindness, notwithstanding the fact that the eyes might be quite intact.

The nervous system and the sense organs so intimately associated with it have been compared with the communications and the general staff of an army. On the distant fronts are outposts which are directly in contact with the enemy and are trying to find out, by sight or hearing, what is happening. These outposts might be compared with the sense organs. Telegraph wires communicate the discoveries to a sub-station, and as a result the officer in command there may send out messages to small bodies of troops. He may, however, also pass the message which he received on to central headquarters, where this and many other similar messages from other sub-stations are co-ordinated, analysed and used as material for a big action in which the whole army is involved and details of which are telegraphed to all parts. The telegraph wires correspond to the nerves, the central headquarters corresponds to the central nervous system, and the sub-stations may be compared to little collections of nerve cells. It is very essential, however, to note a distinct difference in the mechanism of transmission in a telegraph wire and a nerve fibre. In the former an electrical wave can be transmitted in either direction and its speed might equal that of light (thousands of miles per second, although the matter of speed in a long wire becomes complicated). In the nerve fibre the path is a one-way path and the transmission speed is only about 90 feet per second. The impulse-wave in a nerve fibre

is accompanied by a minute development of heat and by electrical phenomena.

We have seen that in the Protozoa like *Amoeba* and *Paramecium* there are neither sense organs nor nervous system. The organism here is a single cell, and all parts of the surface of this cell are equally exposed and equally capable of receiving stimuli to which the protoplasm responds directly. In multicellular animals, where parts are specialised for different functions, a system for conducting and co-ordinating is absolutely necessary, and we find too that only certain parts of the body (sense organs) may be developed for the perception of changes in the environment. The beginnings of such a nervous system are met with in animals like Hydra, but are seen better in the related sea anemones.

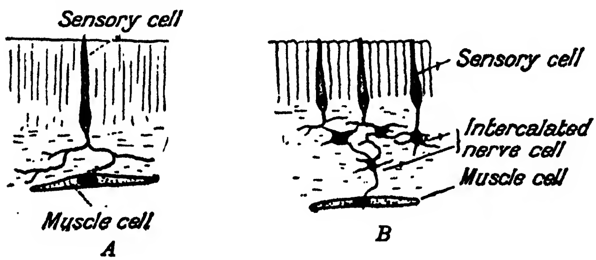


FIG. 135.—Simple types of nervous systems found in sea anemones.
A. Very simple type in which sensory cells (receptors) are connected with muscle cells.
B. More complex type, in which ganglion cells of a nerve net are interpolated between the sensory cells and the muscle cells.[1]

Nervous system of sea anemone

In these animals, long narrow cells are found here and there between the other cells of the outer layer of the body wall (ectoderm layer). The base of such a cell is drawn out into fine processes which run below the ectoderm cells. These cells are the **Sensory Cells** or *Receptors*, and they accept (or are stimulated by) the sorts of stimuli to which an Amoeba responds (contacts and chemical changes in the environment). Below the ectoderm a fine net is formed of the processes of the sensory cells together with processes of another set of cells, which we may call '**Ganglion**' **Cells**,

[1] Recent investigations seem to show that the network is not continuous but that the processes of the different nerve cells make close contact as described for the dendrites on page 264.

and from this nerve net there are fibrous connections to the muscle fibres which are also found below the ectoderm. Two points are to be noticed: (*a*) there is a set of so-called 'ganglion' cells intervening between the sense cells and the muscle fibres; (*b*) the nervous system has the form of a network, and there are no centres and no cord-like nerves (see Fig. 135).

One consequence of this diffuse type of nervous system, from which in all probability the higher types originated, is that a stimulus results in an impulse being sent out in all directions, just as ripples extend from a stone dropped in a pond.

In the earthworm, and also in the crayfish and the insects, the nervous system consists of nerves which con- **Earthworm**

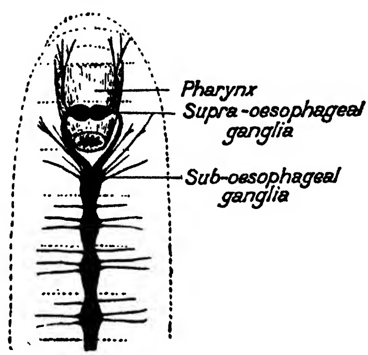


FIG. 136.—Nervous system of earthworm.

nect up little masses of nerve tissue. Two main cords run along the length of the body near the ventral surface (they are so close in the earthworm that they appear as one), and at intervals there are little masses of tissue (**Ganglia**), out of which fine **Nerves** run to the various organs of the body. The largest of these ganglia are situated in the head, and are often termed the **Cerebral Ganglia.** Microscopic investigation shows that the little collections of nerve tissue looking like swellings on the nerves, or the larger terminal masses in the head, are largely made up of nerve cells, and it is a collection of these cells which is termed a ganglion. The grouping together of nerve cells to form ganglia, or larger nerve centres still, is not merely because the cells

are doing the same work. It is more efficient to have centres so that nerve cells may be brought into relationships one with another without long paths between them. The nerves appear to be made up of fibres running side by side. Now what is the relation of the 'nerve cell' and the nerve fibre? Years of investigation have shown that a nerve fibre is just part of a nerve cell—a process of it. The illustration shows one or two types of nerve cells. The difficulty which existed in discovering their shape may be realised from the two pictures (Fig. 138) which show part of the brain, as it appears in a section stained by ordinary methods and as investigated by special technique. In the

Nerve cells

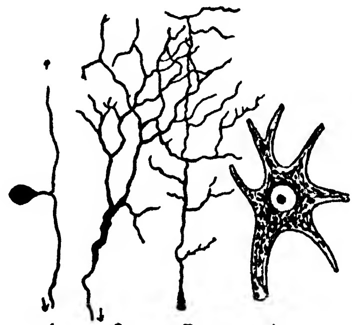


FIG. 137.—Nerve cells.
Various types, 1, 2 and 3; 4 is the cell body more highly magnified.

first case the criss-crossing and entanglement of the nerve fibres renders their deciphering excessively difficult.

The nervous system is built up of nerve cell units termed **Neurones.** Each neurone consists of a cell body (which frequently is called the 'nerve cell') from which a number of branched processes, the **Dendrites,** may arise. One process is of greater length—it may be extraordinarily long for a cell—and is termed the **Axon.** This process is often called the nerve fibre. Numbers of such axons may be bound up to form a nerve. The axon process also ends in a system of fine branches. A single Neurone as described may suffice to bridge the distance between two points in the nervous system. If, however, such is not the case several neurones may form a chain, the dendrites of one

entering into very close relations with the branches of the next in succession. This interlocking junction is called a **Synapse.**

The axons in a nerve may be surrounded by sheaths of cells which are not neivous—they suggest the insulating layers round a telephone or electric light wire. A nerve

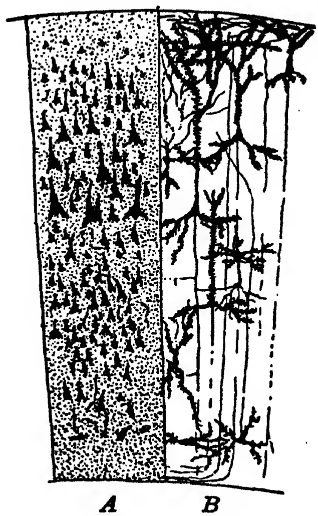


FIG. 138.—Two views of magnified sections of the cerebral cortex (motor area). *A.* as brought out by ordinary staining with haematoxylin and eosin. *B.* as brought out by Golgi methods and other special technique. (Modified after Berkeley.)

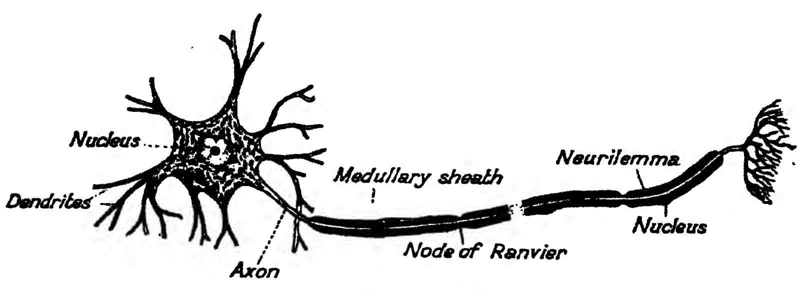


FIG. 139.—Diagram of a neurone.

fibre of this type is called a **Medullated Nerve Fibre** (Fig. 140). The sheaths are two in number, a thick *medullary sheath* (absent at intervals, so that nodes are produced where it is missing) and a covering sheath, the **Neurilemma,** on the outside.

Just as the nerve fibres are the conducting paths and are usually collected in bundles called nerves, so the cell bodies are usually aggregated together and help to form the nerve centres which we term ganglia or, in the higher cases, the brain and spinal cord.

Invertebrate nervous system

We may now look a little further into the structure and functions of the nervous system. In Molluscs like the snail and bivalves, Fig. 141, it consists of a small number of pairs of ganglia connected by delicate nerves. In the earthworm and its allies, the crayfish, the insects, and indeed

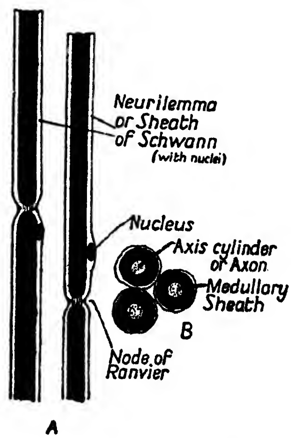


Fig. 140.

A. Diagram of teased medullated nerve fibres (the medullary sheaths have been blackened by osmic acid) from sciatic nerve of rabbit.
B. Transverse section of same fibres. × 900.

almost all the Arthropods, it consists of two solid ventral cords bearing ganglia at intervals. In the head there are a larger pair which may have fused together. From these ganglia nerves run out to the various organs. Into the ganglia, more especially into the anterior one, run nerves from sense organs. This is indeed a very characteristic type of the invertebrate animal's nervous system.

Vertebrates

In the vertebrates the central nervous system is altogether different. It has the form of a hollow tube—the **Spinal Cord**—which is enlarged and complicated at the head end to form the **Brain.** Another difference is that this tubular nervous system is situated dorsally, and is generally protected by the vertebral column.

Great collections of nerve cells are found in the brain and spinal cord, and their processes, that is, nerve fibres, put the different parts of these structures in communication. There are, however, small collections of nerve cells forming ganglia in other parts of the body too.

The Reflex Arc.

If we analyse the complex reactions of the animal nervous system, we recognise certain actions which are direct

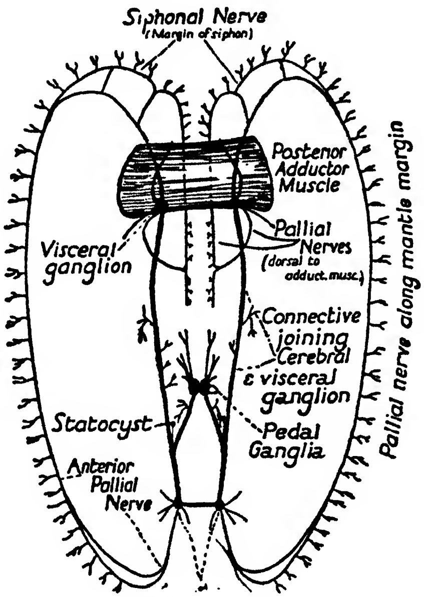


FIG. 141.—Diagram of nervous system of *Mytilus edulis* (common mussel). (The main branches shown by thicker lines can be seen at once by taking a mussel in the hand, pressing back both valves and regarding it from ventral surface.) (After Field.)

responses to the stimuli of the immediate environment. If a sudden movement be made towards the human eye, a sudden automatic blink follows. Touching a frog causes an immediate movement. A sudden noise causes a 'start.' Other movements may follow which are indirect consequences of the stimulus, but it is with the first simple reaction, which does not involve the will, that we are concerned here. This type of reaction is called a **Reflex Action.** It is possible to trace a fundamental type of circuit concerned in the reflex action, and this is called the **Reflex Arc.**

It is easily derived from the conditions met with in Hydra. A simple reflex arc might consist of (1) a neurone which would accept a stimulus from a receptor and transmit an impulse inwards, (2) a neurone whose cell body is generally more centrally situated and to which the first neurone would

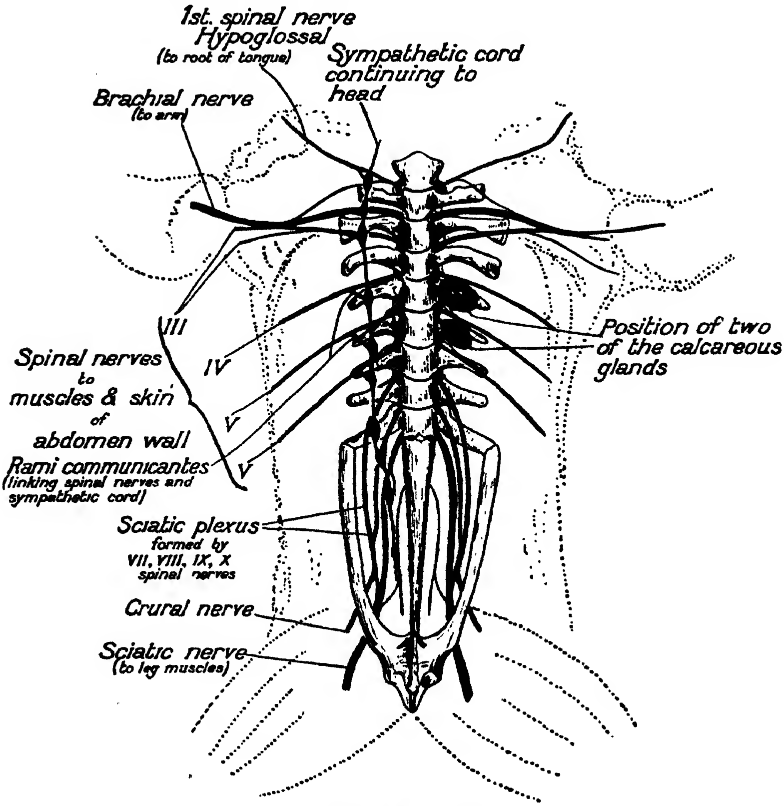


FIG. 142.—Nervous system of frog.

hand over its nerve impulse. This neurone would conduct a nerve impulse outwards again to a muscle fibre or a gland (an Effector) which would thereby be set in action (see Fig. 143).

The first neurone in such a circuit is a **Sensory** or **Afferent Neurone** (made up of sensory 'cell' and sensory fibre—really parts of the same cell). The second neurone is called the **Motor** or **Efferent Neurone** (Motor 'Cell' and Motor Fibre). In a *theoretically* simple reflex action a stimulus

is picked up by one sensory neurone, and a nerve impulse takes the path open to it and eventually reaches some effector. The whole action is thus automatic and direct, there is no question of the will being involved. It is in fact like the ringing of an electric bell in a kitchen by pressing the push outside the front door, and it is well illustrated by the rapid and involuntary blink of the eyelids when a sudden movement is made towards the eyes.

We might consider this example a simple reflex action, because few muscles are involved. It is not, however, nearly as simple as that illustrated by the theoretical path given above. There is indeed no such thing as a simple reflex arc in which only two neurones are involved. It is a scheme, an abstract thing, which is useful in helping us to

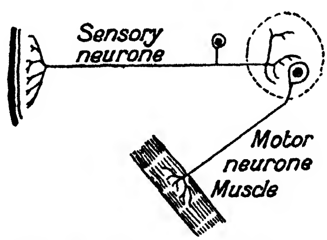


FIG. 143.—Hypothetical reflex arc.

understand the working of the nervous system. The reason for this is easily made clear. It is more natural for a stimulus to affect not one, but a group of sensory endings at once, and therefore several sensory neurones (as in the case of the eye), and in any case the end result is that several motor neurones are engaged.

Reciprocal innervation

A connecting neurone interpolated between the sensory and motor neurones not only brings the former into relation with a group of motor neurones, but the motor neurone is brought into touch with several sensory neurones (see Fig. 145). There is a still further complication which it is important to recognise. It is usually impossible for a muscle to contract without there being an antagonistic muscle which must relax. In the eye reflex, lowering of the lid requires a corresponding relaxation in the muscle for raising the lid. Flexing the arm requires the relaxation of

the muscles which extend it. And thus we have what has been termed **Reciprocal Innervation.** This may be introduced into our theoretical diagram of a reflex arc as shown in Fig. 144.

Our nervous activity is largely built up of these reflex actions, but it is a matter of many co-ordinated reflex arcs. Many skilled movements, which are first made as deliberate and therefore voluntary actions, become by force of habit quite involuntary—a co-ordinated set of reflex actions.

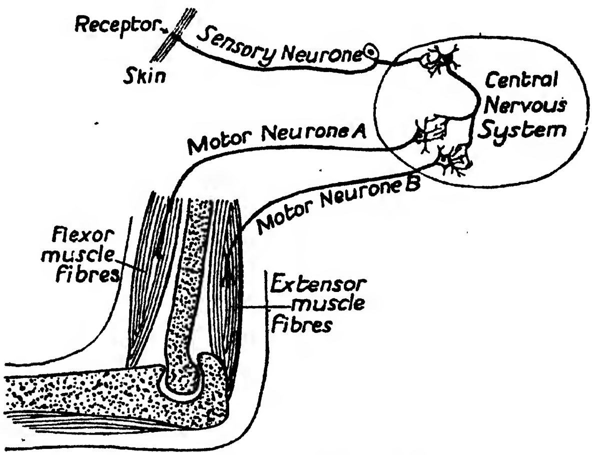


FIG. 144.—Diagram illustrating reflex arc.
The impulse transmitted from the sensory cell (receptor) at the body surface occasions an inhibitory impulse through the motor neurone *B* simultaneously with an impulse through *A*, causing contraction of a muscle fibre.

An excellent example of this is riding a bicycle or walking. We can think out elaborate problems whilst performing either of these actions, yet every minute thousands of nerve 'messages' must be passing from muscle to muscle and through the co-ordinating 'exchanges' in the central nervous system.

From the Spinal Cord of the vertebrates one may trace outwards a varying number of **Spinal Nerves** (a pair leave between every two vertebrae). Each of these nerves arises by two roots, one of which is more dorsal than the other. Before they join, the dorsal root bears a little ganglion. These two roots indicate the separation of the two paths

(the outward and inward), which might be taken by the nerve impulses in a reflex action. The ventral root contains the motor nerve fibres from motor cells in the spinal cord. The cell bodies of the sensory neurones are, however, in the little ganglia on the dorsal roots. Thus each spinal nerve contains two sorts of paths (sensory or afferent and motor or efferent fibres).

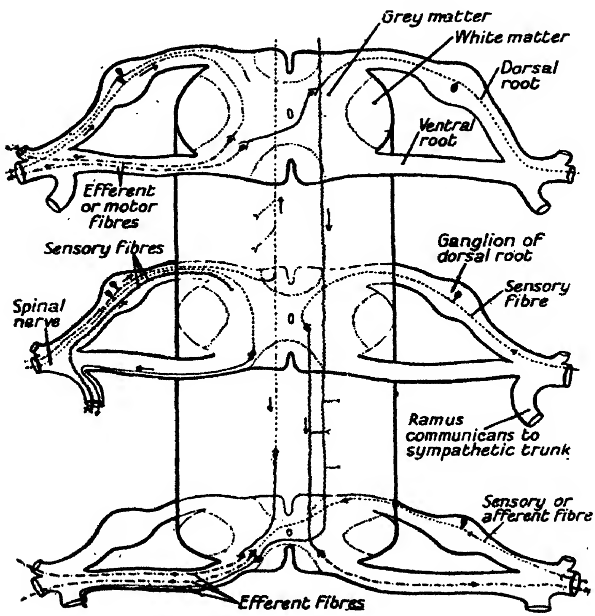


FIG. 145.—Diagram showing a few of the neurone paths in the spinal cord and roots of the spinal nerves.
(Arrows show direction of nerve impulses.)

Now if a sharp point or a hot poker were brought by someone against one's hand unawares, the first result would be a sudden reflex action and involuntary movement away from the painful stimulus. Almost at the same time one would become conscious of the pain, higher centres would be involved and all sorts of complex reactions might follow. Fig. 145 shows how the neurones in the reflex circuit of the spinal cord may be linked up with the higher centres.

Inhibition It is very important to note that although we have spoken above of nerve impulses passing to muscle fibres and glands, exciting them to active work (contraction or secretion), nerve impulses may have the opposite effect—that is, may be messages stopping or **inhibiting** activity.

It must be noted that it is not altogether correct to say that the afferent impulse passes 'inwards'. It is true that the most familiar sensory endings are on the exterior of the body. There are, however, Receptor Organs inside the body, in muscles and joints and in the viscera.

In the invertebrates, like the crayfish and the worm, the ganglia consist of solid masses of nerve cells and their processes. Many of the ganglia are almost identical in structure and function, for the bodies of these animals are segmented and the segments are rather alike. The anterior masses, often called the 'brain,' are more specialised, because they are directly connected with the chief sense organs which are associated with the head. In the vertebrates this specialisation has been developed to a much higher degree—especially in the highest vertebrates and in man. We have already seen that the central nervous **The brain** system in these animals is a hollow tube. The brain forms the highly developed end of the tube. It is differentiated into clearly marked regions, bears certain outgrowths and contains a series of cavities. Thus, taking the frog as an example, the following regions, from before backwards, are clearly indicated: the **Cerebral Hemispheres**, the **Thalamencephalon**, the **Optic Lobes**, a narrow **Cerebellum** and lastly the **Medulla Oblongata** (see Fig. 146). The cavities are indicated in Fig. 146, *C*. The roof of the thalamencephalon bears a peculiar projection (the **Pineal Body**), and its floor is prolonged downwards into a hollow structure termed the **Infundibulum**, to the end of which is attached an organ, the **Pituitary**, which develops independently of the nervous system, and is really a gland.

The nerve cells in the brain are aggregated in definite regions, and to and from these places run tracks of nerve fibres. Where nerve cells are aggregated there is a more or

less distinct colour difference, and the tissue is spoken of as 'grey matter' in contradistinction to 'white matter,' the result of massing together medullated nerve fibres. In the spinal cord the nerve cells lie towards the centre, and thus there is a central mass of 'grey matter' surrounded on the outside by 'white matter.' In the brain the conditions vary in a most interesting manner in the different groups. In the lower vertebrates—fishes and amphibia—the grey matter is largely confined to the inner surface of the cerebrum, lining the cavities, and indeed the roof of the cerebral hemispheres is relatively thin and contains few nerve

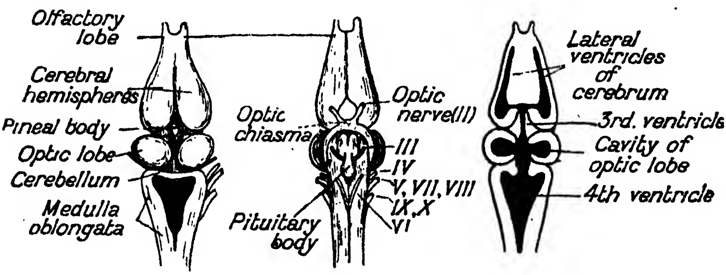


FIG. 146.—Brain of frog.
A. From above. *B*. From below.
C. Diagram showing cavities. (After Wiedersheim.)

cells. Beginning in the reptiles and reaching a climax in the mammals there is a great development of nerve cells (grey matter) on the outside of the roof of the cerebral hemispheres, as may easily be seen by cutting a piece out of the cerebral hemisphere of a rabbit. This layer is known as the **Cerebral Cortex.**

The cerebral cortex

Mental development is associated with great increase in the number of nerve cells of the cerebral cortex, and therefore with the bulk of this layer, and thus one can explain the peculiar and characteristic convolutions seen on the brain surface of the higher vertebrates. Folding is one method of increasing this mass of nerve cell tissue without occupying an unnecessarily large space, thus making the best use of the cranial cavity.

In the cerebellum the nerve cells are close to the surface,

even in the fishes and amphibia, and the same applies to the optic lobes of the midbrain region.

From the brain a comparatively small number of **Cranial Nerves** pass outwards. As these are highly characteristic in the vertebrates and give some indication of the nerve centres within, it will be well to examine them. Their names and regions of innervation are shown in the illustration (Fig. 147).

It has been possible to a great extent to follow the tracks of nerve fibres within the brain, to gain thereby some idea of the location of their cell bodies and the function of the different regions of this great nerve centre. In man and the highest animals the cerebral hemispheres are the organs of intelligence and the seat of conscious sensation. The cortical region, where the nerve cells which are responsible for the highest psychical life of man are found, is, however, the result of a development which, as we have already noted, has taken place in the vertebrate series, for in the fishes the cerebral hemispheres are much more simple, they are practically only olfactory centres. Physiologists have even found it possible to localise certain centres in the human cortex and to discover the parts of the body which they control, but the localisation put forward by the phrenologist is generally quite without scientific basis and often as spurious as fortune telling.

In the fishes and in the frog the optic nerve fibres end in the optic lobes, which are, therefore, the only visual centres. In the mammals these centres still exist, but the chief visual centres are in the cortex of the cerebral hemispheres. Other sensory impulses (auditory, etc.) are also carried forward to the cerebral cortex in the higher groups, impulses entering not only by cranial nerves, but from the trunk and limbs by way of the spinal cord. Thus the cortex comes to be a region where all the sensory impulses reaching the body are correlated and co-ordinated.

Cerebellum It is a more difficult matter to determine the functions of the **Cerebellum,** and there is some conflicting evidence. It is believed that this part of the brain is responsible for the regulation of the complex movements in walking and

balancing. In other words, it is the great 'exchange' co-ordinating the action of many muscles which control the position of the body with different sensory stimuli received from eyes, ears, muscles, etc. In the lower vertebrates we cannot speak with so much certainty of its function. In the frog the cerebellum is very poorly developed.

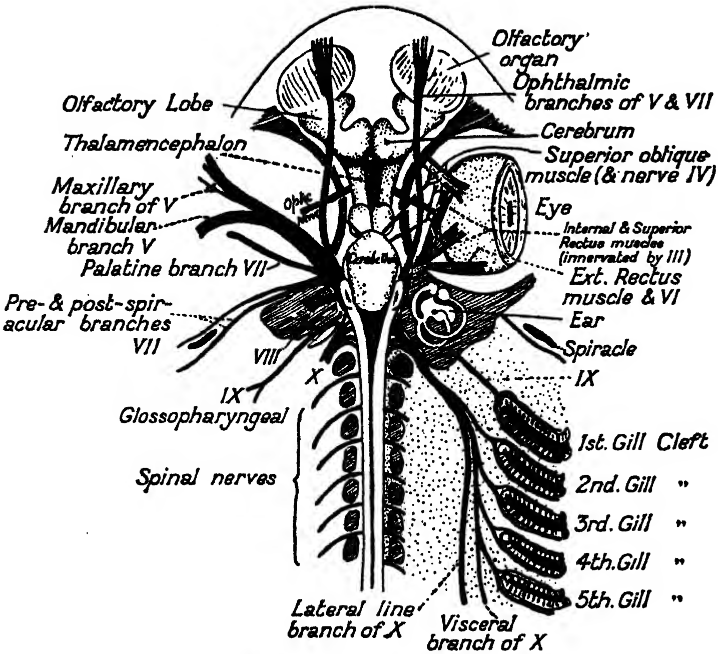


FIG. 147.—The brain and cranial nerves of the dogfish.

The chief centres of the **medulla** are concerned with the control of the respiratory organs and organs of circulation. The auditory nerve (8th) also leaves the medulla. In the dogfish and other fishes the nerve fibres of the lateral line sense organs are closely associated with those going to the ear. In the mammals the auditory nerve contains two sets of fibres, for the ear as we shall see subserves two functions. One set (the real auditory fibres) pass through the medulla to the roof of the midbrain, the others go mainly to the cerebellum. **Medulla oblongata**

To complete our brief account of the nervous system it

Sympathetic nervous system

is necessary to refer to a system of nerves and ganglia, which is termed the **Sympathetic Nervous System.** The main portion of this is easily seen in the frog, where it lies as a longitudinal trunk running parallel to, and on each side of, the dorsal aorta. It is connected by short branches to each spinal nerve, and there is a little ganglion at each such junction. In front it enters the skull and is connected with the 10th and 5th cranial nerves and ends in a ganglion of the latter (Gasserian Ganglion). From these sympathetic ganglia small nerves run to the viscera. Now the Sympathetic Nerves are really special paths for nerve fibres which run to organs not under voluntary control. They run to the heart, the intestine, to muscles and glands and, in fact, to all involuntary muscles of the body, and they tend to form great networks or plexuses on certain of these organs. It is a curious fact that most of the nerve fibres of the sympathetic system are without medullary sheaths.

We have given a very brief résumé of the chief centres in the central nervous system of the vertebrates. It is impossible to give even the chief centres for the invertebrates. Experiments on the crayfish, crab and the insects have enabled us to trace regions of the so-called cerebral ganglia, which are centres for vision, and there are ganglia associated mainly with different limbs. But when one thinks of the remarkable complexity of the sense organs of some of the invertebrates and of their acuteness and behaviour, one marvels at the simple masses of nerve cells which are responsible for it all.

Practical work on nervous system

I. The student should dissect out the brain and nervous system of the dogfish (or ray) and the frog. The illustrations (Figs. 146, 147) clearly indicate the position of the nerves and the names of the parts. The fundamental plan of structure should be noted and a comparison made of the different types.

II. Make dissections of a number of invertebrate types. The nervous system of the crayfish, an insect, the earthworm, snail and a common mussel should be examined and compared.

III. Examine a rabbit's brain or sheep's brain in detail.

Note the distribution of grey and white matter. The illustrations (Figs. 251 and 252) indicate the parts which ought to be seen.

IV. Take a piece of sciatic nerve from the frog, tease it out in salt solution and notice the structure (see Fig. 140). Add a drop or two of stain and sketch. This nerve is medullated as are all the spinal nerves of vertebrates. The invertebrate nerves are non-medullated.

V. Take a piece of fresh spinal cord from the ox and notice the cut ends. (Position of grey matter inside and white matter externally.) Place a little of the grey matter in a mixture of 2 c.c. Formalin (as sold) in 1000 c.c. of 0·75% salt solution for a few hours until it is macerated. The ganglion cells can now easily be dissociated by placing a little piece of the tissue in salt solution under a cover glass supported slightly (by one or two hairs), and if necessary tapping above it. To stain the cells the tissue should first be washed in water. After separating the cells under the cover glass an aqueous stain should be run under (see page 461).

VI. Note the effect of touching one, and then several tentacles of an expanded sea anemone in a salt water aquarium. A strong stimulus is conducted in all directions from the part touched, a weak stimulus perhaps produces a local reaction only.

VII. Demonstrate the knee-jerk reflex. One person should sit on the edge of a table with one knee over the other. A light blow is struck upon the ligament just below the knee cap. The leg responds with a jerk. This is not due to direct stimulation of the muscles involved. A reflex arc is present involving the spinal cord. Try same experiment after subject has clenched fists. Notice that response is more marked. The degree of response depends upon condition of body, and is utilised by physicians as indicating condition of nervous system.

XIV

THE SENSE ORGANS

We have seen that the muscles and glands respond to impulses conducted to them by the nerves, and that these impulses are the direct or indirect consequences of stimuli received by the nervous system. Even in such a simple type as *Hydra* certain cells of the outer layer were seen to be specially set aside for this reception of stimuli. In the higher animals (but beginning in the group to which *Hydra* itself belongs) there is not only a variety of such receptory cells, but they are often aggregated into special areas of high efficiency. As a result of this the reception of stimuli is not uniformly possible over the whole surface of the body, but is localised in particularly suitable parts, the **Sense Organs,** where these receptory cells are developed. The sense organs range in complexity from a mere aggregation of sensory cells with perhaps a few supporting cells up to such structures as the vertebrate eye and ear,[1] in which there are not only sensory elements, but complex arrangements for promoting such efficiency as enables us to recognise objects a long way off and to estimate their distance or to analyse and appreciate the accumulation of sounds produced by an orchestra.

The sense organs ' are the doors through which stimuli of the outer world enter the body,' and the greater their efficiency and the greater the diversity of stimuli, the more exciting does the environment become and the more highly developed is the nervous system which is so closely bound

[1] The reception of stimuli by special nerve endings or cells does not always produce a sensation, and so it might be better to replace the term Sense Organ by the word **Receptor.** This would serve for organs like the eye as well as for the receptive structures in muscles and in other parts of the body.

up with them. Sensory endings are, however, not confined wholly to the skin. There are receptors in the alimentary canal and other internal organs, and an important distribution in muscles, muscle tendons and joints. The latter are all concerned in the judgement of weight, and the proper co-ordination of complex muscle movements.

We often speak of the *five* senses—meaning sight, hearing, taste, touch and smell. It is clear from the above that we possess others, and the sense of touch is itself divisible into several types of perception. Nor does it follow that these senses shall all be found in the lower animals or that, if present, they should be developed to the same degree as in man. They may be more keenly developed (smell in the ants and the dog, sight in birds, hearing in various animals, touch in the bat, and so on) or much less so, and the positions of the sense organs on the animal may be equally diverse. How it comes about that the protoplasm of certain cells responds practically only to light, that of others only to vibrations, and of others again only to chemical variations in the environment is unknown. But the protoplasm of all specialised cells has its own peculiar qualities.

Sense of touch

Sensory cells for the perception of contacts with external objects are met with amongst the lowest multicellular animals. Although they may occur over a wide area of the animal's body, they are often aggregated in special places, which are then said to be more sensitive than others.

In *Hydra* they are long narrow cells amidst those of the outer body wall, and they are more numerous on the tentacles than elsewhere (Fig. 38).

The earthworm represents a more advanced stage. The sense of touch here is probably mediated by fine nerve endings amidst the ectoderm cells, but numerous sense cells are present. Earthworms not only respond very definitely to contact stimuli, but use this sense for the determination of objects, such as the leaves which they pull after them into the mouths of their burrows.

The Crayfish and the Insects which are covered with hard shells of chitin have their sense organs more restricted and concentrated at certain places. In the Crayfish touch

sense organs are present on the antennae and on all the other appendages as well as on projections of the body and at the joints. They consist of touch bristles which are connected internally with fine nerve fibres. In aquaria, crayfish generally get into a corner or hole. This behaviour has been put down to a habit of having as much contact with the more 'solid' immediate environment as possible. The antennae are very sensitive, and it is difficult to reach

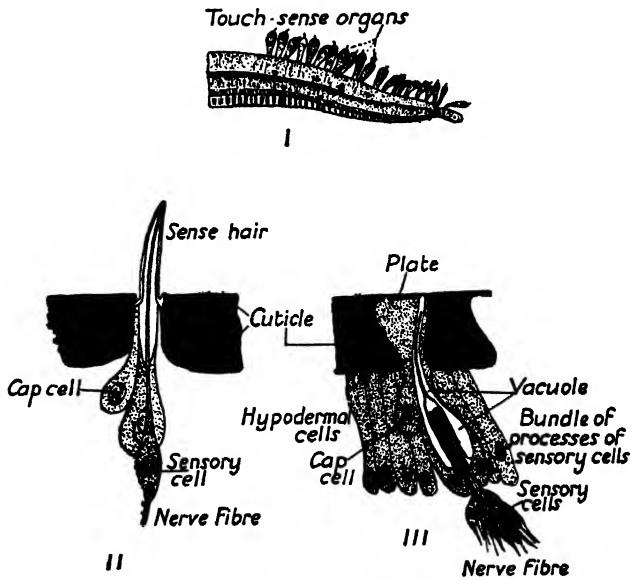


FIG. 148.—Sensory cells of insects.

I. Diagram of tip of proboscis of cabbage white butterfly with touch sense organs. (After Schoenichen.)

II. and III. Sense organs from antenna of honey bee. II. Hair Organ. III. Plate Organ. (Modified after Snodgrass.)

and touch them without first producing some response through the setting up and the perception of movements in the water.

Varieties of touch and sense

In Man the tactile structures in the skin are specialised, so that there are different receptive endings which mediate —pressure contact, warmth, cold and pain. Our touch sensations are usually compound, for several of the sensory spots are involved at one time. It is quite possible to determine the position of these sensory structures if the skin is touched with a fine needle. Pressure on certain

spots gives mere contact, equal pressure on others gives a sharp feeling of pain, whilst if the point be warmer than the skin, say above 38° C., the warmth endings may be stimulated; if the point be colder than the skin, say 26° C. or less, the cold spots are stimulated. Thus we see that it is not the whole surface of the skin which is sensitive. The pain spots appear to be most numerous, the pressure spots next, and those for warmth least numerous. It *is* possible to stimulate some of these sensory spots with the *wrong* stimulus, and the result is the same feeling that one would have experienced with the correct stimulus. Thus menthol stimulates the cold sense endings, and its touch feels cold.

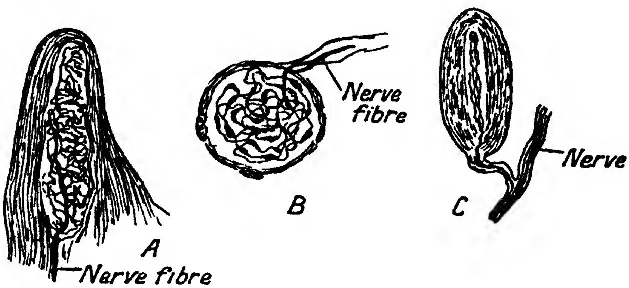


FIG. 149.—Sense organs from skin and muscles (human). Highly magnified.
A. Touch corpuscle from skin.
B. End bulb of Krause—skin and conjunctiva.
C. Pacinian corpuscle from connective tissue of muscles.

The pressure spots are often situated in connection with the root of a hair, and thus contact and movement of a hair is clearly appreciated and a slight pressure is intensified. These sensory structures are most common on the tips of the fingers and least numerous on the middle of the back. One can form some idea of the closeness of the distribution of these little sensory spots in the human skin by blindfolding a person and touching the skin simultaneously with the two points of a pair of dividers. It will be found that the two separate points can be distinguished better by the skin of the tips of the fingers than by the back of the hand or the middle of the back. Naturally the sensitivity varies with different people, but figures have been given showing that whereas the two points could be distinguished by the

tips of the fingers when only ⅛ in. apart, the points of the dividers had to be 2 in. apart for the same recognition by the skin of the back. The pain sensory endings are present not only in the skin, but also in many other parts of the body—in the viscera, for example.

Allied to these cutaneous touch sensory spots are others situated in the muscles for the perception of muscle stimuli. These latter are involved when we estimate the weight of an object which we are holding. They probably play a big part in the co-ordination of muscle movements.

As to the actual structure of the sensory spots, some are probably fine nerve branches from sensory nerve cells ending

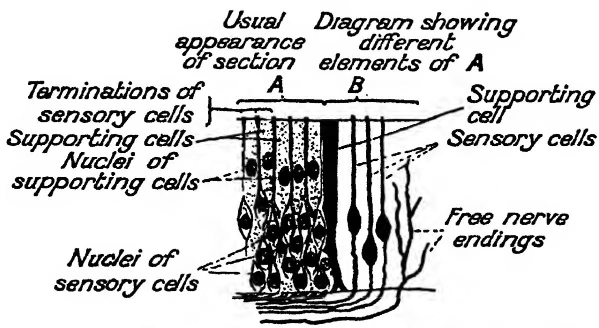


FIG. 150.—The olfactory epithelium of a mammal with olfactory sense cells. Diagrammatic. Highly magnified.

amongst the cells of the skin (free nerve endings); others are quite complicated little structures—so-called **Touch Corpuscles** which are built up of many cells (Fig. 149). It is not so easy to determine which of the sense qualities described above is correlated with any particular type of structure. Probably the pain spots are sensory structures of the free nerve-ending type. Pressure is probably effected by touch cells and the sense corpuscles, and likewise the cold and warm stimuli, but there is no absolute certainty about the latter.

Skin sense organs of the type mentioned above are particularly common on some animals—the nose of the mole and other mammals where the long bristles (whiskers) are associated with them, and also the bill of the duck.[1]

[1] It has been estimated that there may be about 15,000 pressure receptors on a human finger-tip.

Whilst we instinctively separate these two senses, because in man they are mediated by sensory structures in two different places (the nose and the mouth), they are not so easily separated in other animals. In both taste and smell the stimulus is of the same type, a chemical stimulus. In taste the substance affecting the sense organs must be a solution or be soluble in water, whilst in smell the substances must give off fine particles—probably in gaseous form—and these are dissolved in the mucus. It will be seen therefore that it is difficult to speak of smell in the human sense in connection with aquatic animals. Although **The senses of smell and taste**

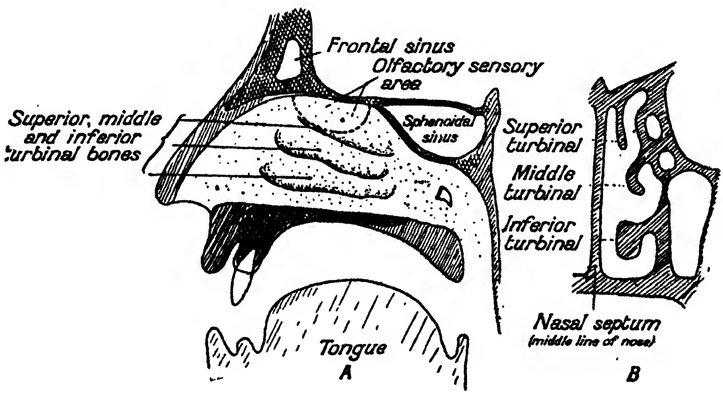


FIG. 151.
A. Diagram showing relation of mouth, nasal cavity, etc., in man.
B. Diagram of transverse section through half of nose (man). (After Parker.)

the two senses are thus fundamentally the same, different types of sense endings are involved in the sense organs, and there are different qualities in the appreciations.

The olfactory sense in man is mediated by a series of epithelial cells, each of which is long and columnar and terminates at the free margin with a tuft of 6-8 hair-like processes (Fig. 150). At the lower end each cell projects as a nerve fibre, which is continued along the olfactory nerve to the brain. Amongst the sensory cells are a number of columnar supporting cells. The olfactory sense organ is thus built up as a simple layer of sensory cells. The layer of cells lies on the septum and certain coiled bones in the nose (Fig. 151). Substances which smell must, of **Sense of smell**

course, give off particles which can reach this area of cells, and this may be by active drawing in of air (sniffing) or by simple diffusion. It is not necessary that the entrance be by the nostrils. It may be by way of the posterior nares from the throat.

It is really surprising how many well-known food substances cannot be tasted if the nose is blocked or held shut. This is because many flavours that we think we taste are really smelt—their emanations pass up to the olfactory cells as the substances are swallowed. It is possible to cause fatigue in the olfactory apparatus, just as in the

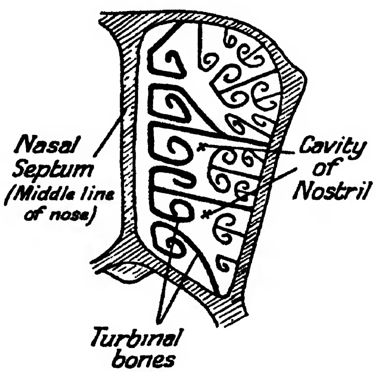


FIG. 152.—Diagram of transverse section through half of nose of mammal with complex turbinal bones. (After Hesse and Doflein.)

nervous system and the muscular system, by long continued action of the stimulus. Thus a newcomer may notice odours in a room which are not perceived by one who has been working in them for some time.

The olfactory sense organ of the dog is, of course, exactly of the type described above. It is, however, much more sensitive than that of man. If the skull of a dog be examined, it will be found that there are complex scroll-like bones in the nasal cavities. The area of olfactory sense cells is greater than it is in man, although it does not cover all these bones.

In a number of mammals the sense of smell practically becomes the most important of all the senses. On the

other hand the frog possesses only a poorly developed organ of smell.

In the fishes the nasal apertures obviously conduct water to the olfactory sense cells, and thus there is a resemblance to the sense of taste. Probably the chemical stimuli appreciated by these cells are different from those affecting the taste sense organs of the lips.

Smell in Invertebrates

In the diverse groups of aquatic invertebrates, it is almost impossible to differentiate the senses of smell and taste, and it is often better to combine them and to speak of a **Chemotactic Sense.** In air-breathing invertebrates these two senses may again be considered apart, as in the insects where the sense of smell is most highly developed.

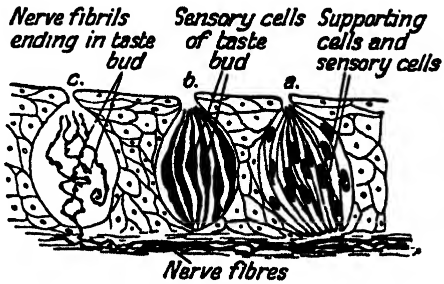


FIG. 153.—Taste buds on human tongue.

The sense 'organ' consists of groups of sense cells forming little organs of varied types situated on the feelers or antennae. The acuteness of the sense is in some cases absolutely marvellous. Ants recognise the inhabitants of their own nests and find their way from nest to feeding place by this sense.

The wasp—*Rhyssa persuasoris*—lays its eggs in the living larvae of an insect which lives and bores inside pine stems. It is said that the wasp bores down correctly to the place where such a larva is lying—that is, that it must have smelt it through the wood.

The most surprising feats of all are those in which one sex in the butterflies will seek out the other by smell. Thus two Swiss scientists, who had bred the females of certain related moths, found the males attracted to the windows

in such numbers as to excite the attention of passers-by in the streets. Some of these moths must have come more than a mile. The human being could not detect any smell at all even with large numbers of the insects close at hand.

The sense of Taste is mediated by sense organs which are found in man on the tongue, part of the palate and other regions of the mouth and pharynx. They are usually termed taste buds. Each bud consists of a number of non-sensory cells ensheathing a mass of elongated cells, each with a little hair-like process which projects through a pore left between the sheathing cells. The hair-like processes are probably the parts which receive the stimulus.

The sensory nerve fibres are *not* continuous in this case with the cells which receive the stimuli, but form a network round them. (See Fig. 153.)

These very characteristic sense organs are limited to the mouth in mammals and other air-breathing vertebrates, but in the fishes they occur not only in the mouth, but especially on any processes in its neighbourhood and even elsewhere on the surface of the body.

In the invertebrate animals it is not possible to detect any sense organs directly comparable to taste buds such as these, but in aquatic animals there are frequently sensory cells for the appreciation of the quality of the water, and everywhere one meets with simple sense cells for the appreciation of chemical changes (chemotactic sense). The Anemone tentacles react to food. The earthworm will react to chemical substances over the whole surface of the body, but it is particularly sensitive at the head and tail ends, and probably the sense cells enable the worm to distinguish one kind of leaf from another, because certain of them seem to be preferred.

Molluscs like the bivalves and univalves can certainly appreciate flavours in the water in which they are living. Squirting minced starfish into an aquarium where scallops are living will set all of them swimming about in great excitement.

In the crayfish, lobster and crab there are certainly chemotactic organs, and the quality of the bait plays a

big part in catching them in traps. A decaying fish dropped into moderately shallow water may soon be found covered with shore crabs which have undoubtedly been attracted by flavours spreading through the water. Probably in these animals the sense organs are situated on the antennae.

In the insects taste organs are found on the mouth appendages (the proboscis, etc.), and in the oesophagus wall, but, as we have seen, the sense of smell is distinctly developed in insects, and it probably plays a greater part in the search for food.

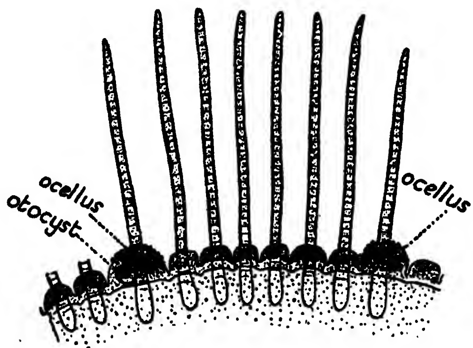


FIG. 154.—Part of margin of an Obelia medusa, showing ocelli and statocyst (otocyst in Fig.). (Number of ocelli on complete medusa about 24, statocysts 5-8 only.)

The sense of **Orientation** is one of the most universal in the animal kingdom, although it is not often recognised by the general public. Yet there is a well-developed organ for this function in man. **Orientation**

We commenced our study of the sense organs of taste and smell with man, because they were best known there. In the case of orientation we may begin with the lower animals. We first meet with organs of orientation in the jellyfishes, and at once find that the fundamental characteristics of these organs are present. Generally the sense organ consists of some kind of a solid 'heavy' body—a statolith (secreted by the animal or else sand grains picked up)—resting upon a number of stiff processes from sense cells. There are various little differences in the jellyfishes, but the essentials are illustrated in Fig. 157.

One can easily see how they function. So long as the jellyfish remains in one place, the statolith rests on certain cells. If the jellyfish turns over, or one side lies higher than the other, the statolith will fall over on other cells. In all probability these movements of the statolith release reflexes which cause this or that group of muscle fibres to contract more vigorously, so that the movements of the little bell are modified. In this simple way the animal adjusts its position with regard to the vertical. One can realise that for aquatic animals, which touch and are supported on all sides by the medium in which they live, this is even more essential than for terrestrial animals. Animals without means of locomotion—those fixed to the

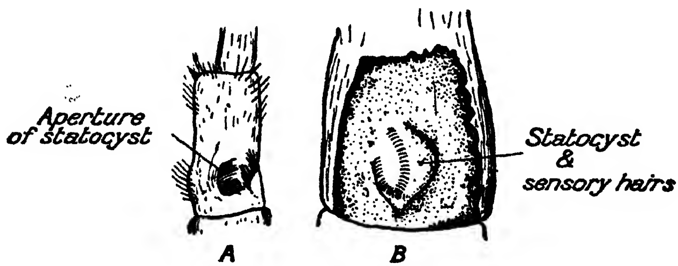


FIG. 155.—Statocyst from crayfish.
A. External view of aperture. *B*. Wall cut away.

rocks, etc.—will not be likely to have well-developed organs of orientation, and one would not expect such in Hydra or the Anemones.

There is no special organ of orientation in the earthworm, but many marine worms have two little spherical chambers lined with sense cells which support statoliths in the same way as the above, and the same kind of structure is met with in the mollusca.

In the crayfish and lobster there is a well-developed organ for orientation. In these animals the little chamber (the **Statocyst**) is found at the base of the 1st antenna (antennule). The chamber is lined by cuticle, from which hairs project which possess an internal nerve fibre. The statoliths, of which there are several, are sand grains which enter the chamber or which the animal causes to enter.

In a related animal, the prawn, the function of this organ was neatly studied by an experiment which depended upon the fact that each time a crustacean casts its shell, the lining of the statocyst is also shed, and consequently the sand grains are lost. The animal has to obtain a fresh supply before the statocyst will function. A prawn which had thus cast its shell was kept in water absolutely free from sand and given finely powdered iron instead. Failing to obtain other fine particles, some of these iron filings were introduced by the animal into the statocyst. The result was that when a magnet was brought near the animal the particles of iron could be made to

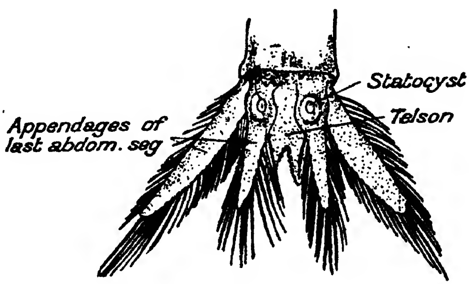


FIG. 156.—Statocysts of *Mysis*.

press on different sense cells of the statocyst just as if the normal animal with sand grains had been turned over. The force of gravity was replaced by the attractive force of the magnet, and by this means the prawn was made to change its position according to the movements of the magnet. The statocysts were clearly shown to be organs for orientation.[1]

In the vertebrates from the fishes to man the organ of orientation is found in the ear, which has therefore two sense functions. The part concerned with the sense of orientation consists essentially of three semicircular membranous canals which communicate with a chamber (**Utriculus**). A brief description of the whole structure of the

[1] Another crustacean in which the statocysts can be very easily seen is *Mysis*. In this case, however, they are situated in the last abdominal appendages (see Fig. 156).

vertebrate ear is, however, necessary before we can explain the part which acts as the organ of orientation, and so the discussion of the latter is postponed to page 293.

An excellent model of a Statocyst can be made from an indiarubber ball, a small brass ball, some screws and an electric battery and bells. The illustration gives the necessary details.

A piece of the indiarubber ball is cut away so that the brass ball can be inserted in it. On two or three areas of the rubber ball a number of brass screws are put through about ½ in. apart and with the heads inside. These are connected up with copper wire to the bells and battery in such a way that

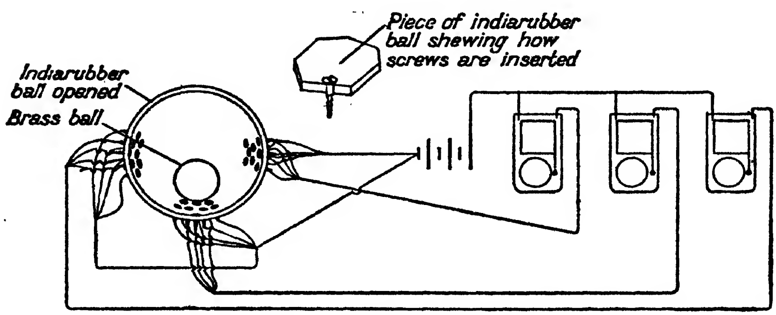


FIG. 157.—Model of a statocyst.

the brass ball falling on the heads of adjacent screws will complete a circuit and ring a bell. The brass ball corresponds to the statolith, the screws to the sensory cells.

The Sense of Hearing.

If by hearing we mean the perception of vibrations of certain frequency in the air as distinguished from the perception of vibrations of long wave length in water or in the soil, the sense of hearing is practically restricted to the vertebrates, and the insects alone amongst the invertebrate animals. It was formerly doubted whether fish could hear, although they certainly possess sense organs which correspond to part of the human ear. Recent researches show that not only do they hear, but that they can distinguish between different tones. It will be noticed that some insects possess organs for the production of sounds; it is, therefore, not surprising to find organs for the percep-

tion of sounds in this group (see Fig. 158). The most common examples are the grasshoppers and crickets, which make characteristic noises. Female crickets can even distinguish males by the sounds.

The vertebrate ear

The human ear will serve as an example of the most highly developed vertebrate ear. For comparison, examination should be made of the auditory organs of the frog and the dogfish. In the mammals the ear comprises three parts. These are the external ear (the lobe or **Pinna,** which is a sound collecting instrument like an ear trumpet), the middle ear and the inner ear. The middle ear is a passage or cavity in bone, with the ear drum (**Tympanic Membrane**) across its outer aperture and with a tube (**Eustachian Tube**) leading down to the pharynx. From the ear drum a chain

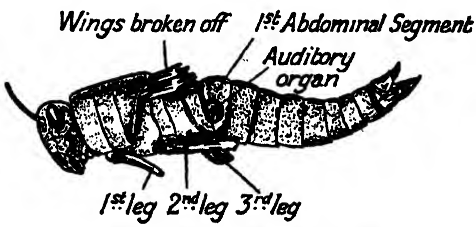


FIG. 158.—Grasshopper from side, showing position of tympanic membrane.

of ossicles leads across the cavity to a membrane forming a window across a small aperture which communicates with the cavity in which the inner ear lies. The inner ear consists of the actual sense organ, the bag-like membranous ear, of complicated shape, which is surrounded by bone so that the cavity in this bony case is equally complicated in shape. For this reason the bony case has been known as the **Bony Labyrinth** and the actual sense organ as the **Membranous Labyrinth.** The membranous bag consists of two chambers, the **Utriculus** and the **Sacculus.** From the utriculus three little canals run out in the form of semicircles. They lie in three different planes at right angles to each other. At one end of each canal there is a swollen part (the **Ampulla**), and within this are sensory cells with long processes (see Fig. 160). Other sense cells are found in the utriculus and sacculus. Lying amongst the

hairs of these sense cells are limy secretions called Otoliths. In the fishes there are large flat plates of bone-like consistency also called Otoliths, lying by the Sacculi. The sacculus is, however, the true organ of hearing in the fish. From the sacculus there projects one long outgrowth, which is spirally coiled and is known as the **Cochlea.** This contains a most remarkable sensory structure, which is obviously the organ for hearing in the highest sense, the perception and analysis of sound waves. The inner ear contains a fluid—

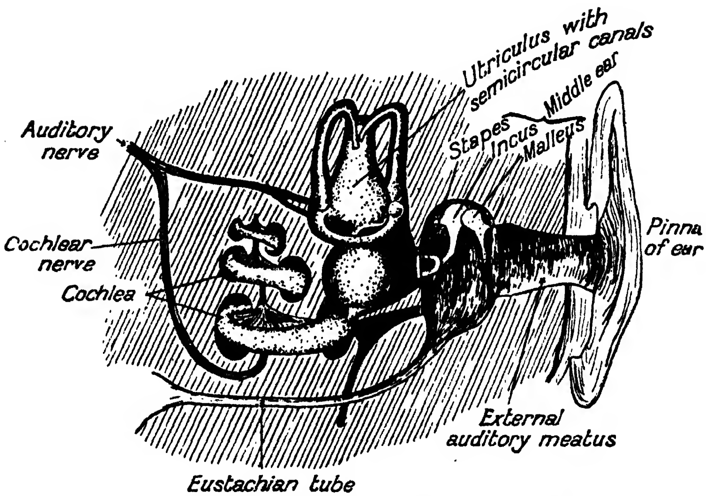


Fig. 159.—Diagram of mammalian ear. (Modified after Kingsley.)

the **Endolymph**—and the sac itself is bathed in fluid—**Perilymph**—which lies between it and its bony case.

Comparison of human ear and that of lower vertebrates

In the birds and reptiles there is no ear lobe or pinna; the opening seen on the skin surface leads to the ear drum. In the frog, even this part of the outer ear is missing, and the drum is level with the surface, visible below and behind the eye. The chain of ear bones is missing also, and their place is taken by a single bone which plays the same function. The great difference, however, lies in the development of the cochlea. This very important part is less developed as one passes from man downwards, and is almost absent in the frog.

In fishes the ear consists only of Sacculus, Utriculus and

Semicircular Canals. The outer and middle ear are both absent, and the cochlea is represented by a rudimentary projection of the sacculus. As there is no ear drum, vibrations can only reach the sensory cells by passing through the flesh and bones of the head.

How the ear functions in mammals

Orientation.—Very interesting experiments have shown that the semicircular canals and utriculus play important functions quite different from the perception of sound. Animals may be quite unconscious of this, for the sense organs found in these places may simply release reflexes in the nervous system and work unconsciously. It has been

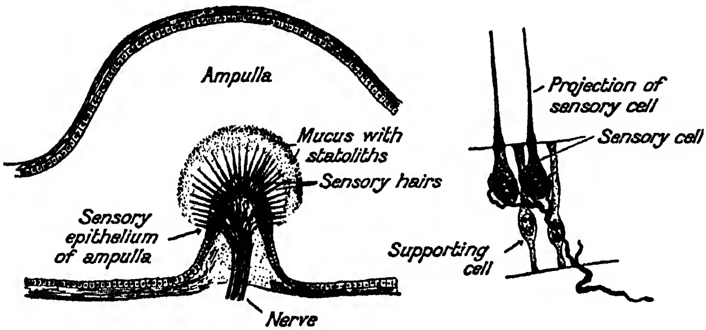


FIG. 160

A. Section through ampulla of ear.[1] Magnified.
B. Highly magnified view of portion of sensory epithelium from *A*.

found that movements of the body, by turning to right or left, or progressive movements up or down, side to side and so on, are all followed by quite automatic reactions of the head, the eyes, or even the muscles of the limbs. These reactions are occasioned in great part by reflexes from the semicircular canals. Again, the position of the body of an animal in regard to the vertical occasions definite states in the muscles of the body. For example, if a rabbit be held free in the air after destruction of the otoliths, it is completely disorientated, that is, its responses show that it makes no difference whether it is upside down or on one side or another. Lay it on the ground, however, on one side, and it immediately makes the usual reflex head movement characteristic of this position. Contact has, therefore,

[1] The term Statolith is sometimes used instead of Otolith.

made up for the loss of the otoliths. Proof of this is found by pressing something against the other side of the body of this rabbit lying on the ground. The contact on both sides neutralises this effect, and the animal is once more dis-orientated.

To put the matter briefly, the normal animal in, say, a standing posture keeps its position by the action of many muscles as the result of a co-ordinated series of responses to stimuli from the environment. These stimuli are partly visual (the animal observes its position), partly due to touch sensations, and are partly due to the orientating action of the otoliths in the utriculus.

If a cat be held up by its four paws so that its back is towards the ground, and then is dropped, it is well known that a remarkable turn is made in mid air, and the cat not only lands on its four paws, but the limbs are just in the rightly stretched out and tonic state to receive it. It has now been shown that the turning of the falling cat is automatic, and is due to a series of reflex actions probably initiated entirely by the orientating organs of the ear. A cat or dog with ear labyrinth destroyed on both sides falls anyhow and heavily, *even* though its eyes be uninjured and it has their help to orientate itself.

So much for this curious work of the ear in helping us to keep our equilibrium.

Sense of Hearing.—In the fishes and lower vertebrates the action of sound waves in setting the otoliths of the sacculus in motion, results in hearing. However, the perception of sounds, as we understand it in the case of man, the perception of tone quality, etc., is due to an elaborate sense organ developed in the cochlea. In mammals the sounds are concentrated by the outer ear on to the tympanic membrane, which is set vibrating. These vibrations are handed across the middle ear by the chain of ossicles (see Fig. 159) and thus set up vibrations in the inner ear. We cannot enter upon a description here of the mode of action of the cochlea. In all probability, however, the sensory cells in that structure respond to different notes, just as a tuning-fork will respond to its note sounded by another tuning-fork.

The different functions played by the mammalian ear are so distinct that it is not surprising to find that the nerve fibres from the cochlea end in a different centre in the brain from those of the utriculus and semicircular canals. Thus the ear is a complex sense organ and in addition to being a sound receptor it is (1) an organ concerned in maintaining muscle tone ; (2) an organ concerned in orientation and equilibrium—in the maintenance of efficient body posture.

Vision and Visual Organs.—To the normal human being the sense of sight means the possibility of recognising clearly and distinctly not only the form of the surrounding objects, but also their colours. It is well known, however, that owing to defects there are numerous people who cannot see clearly without the aid of spectacles, and there are many who see form distinctly but are colour blind, that is, cannot perceive certain colours as the normal person sees them. It is probable then that other animals may see distinctly yet may not recognise colours. In fact, every possible grade exists from the full power of colour vision of the normal human being down to cases where the animal certainly reacts to light, but is not able to do more than distinguish between light and darkness, perhaps to perceive a shadow falling on it ; the form of objects is not recognised at all. Where visual perception is as low as this, there may be no distinct sense organs that we could term eyes, or little black spots may be visible which are merely collections of pigment in or around sensory cells. The latter is the most simple type of visual organ found in the animal kingdom. **Sense of sight**

The protoplasm of cells which are specialised as receptive cells for light waves is evidently modified, and probably contains substances which are chemically and physically altered by light. There is now no question that light rays, especially those of certain wave length, exercise a great influence on living protoplasm, and possibly they are absolutely necessary for the normal development of the body in many animals quite apart from such a matter as the sense of sight (cf. Chapter III, Rickets).

In *Hydra* there are no specialised sense organs for the perception of light, but by keeping specimens in an aquarium which is lighted on one side, it can easily be shown **Sensitivity to light**

that the *Hydra* cells are sensitive to light rays, and that the Hydras tend to collect towards the window side.

In the jellyfish, animals related to *Hydra*, there are often collections of cells which contain pigment, and are known as **Ocelli.** At certain points on the outer rim of the jellyfish there are little groups of sense cells, from each of which a process runs inwards to the nerve network. Between these sensory cells are columnar supporting cells which contain granules of pigment. The little group of cells forms an ocellus, and we may regard it as the first stage in the development of an eye (see Fig. 154). In some cases, even in

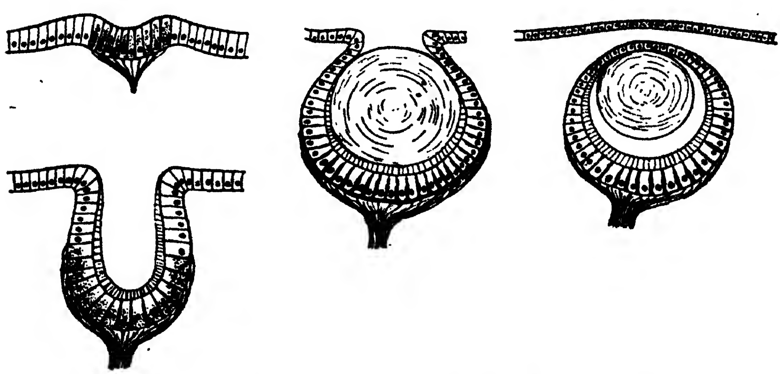


FIG. 161.—Diagrams illustrating different types of invertebrate eye structure. Note the different degrees of complexity.

this lowly group, there is a kind of lens developed as a secretion from the cells. There can scarcely be any question of its forming an image—it probably merely concentrates the light on the sense cells. This visual organ in the jellyfishes probably plays a similar function to that of the statocysts, and helps the organism to keep a horizontal position in the sea water. It will be evident that, if the animal becomes tilted, the light rays will strike the cells at a different angle, and some ocelli will be less illuminated than others.

Many scientists have described the reactions of the common earthworm to light, and all agree that the animal is very sensitive and that it moves away from an illuminated area to the shadow. As a matter of fact it is only at night

that earthworms actively leave their burrows and wander on the surface of the soil. The sensitivity to light rays is present to some extent in the whole skin surface, but it is very much more strongly developed at the extreme anterior end. No definite eyes are present in the earthworm, and this sensitivity to light must therefore be due to nerve endings amidst the ectoderm cells or else to special cells of this layer.

Many marine worms (like Nereis, which is common under stones at low tide) have very well developed eyes, but it is

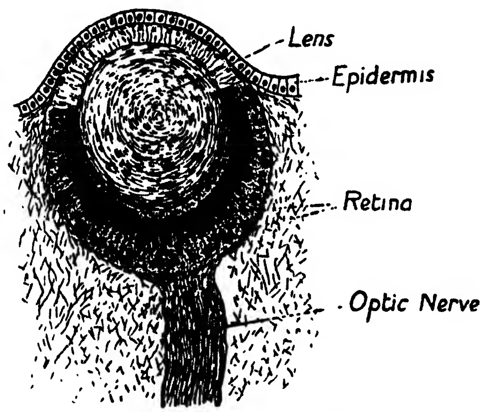


FIG. 162.—Section through eye of snail.

improbable that they perceive more than variations in light intensity.

The diagrams illustrate the possible method by which such a simple collection of visual sensory cells as seen in the jellyfishes and other invertebrates may develop into a more efficient eye. Note in particular how the series of grades leads to the development of a closed chamber. All these types are actually met with amongst invertebrates, and a great many in the group Mollusca.

The Snail is an example of an intermediate stage. This animal has two eyes, one at the end of each of the 2nd pair of tentacles. Each eye consists of a little completely closed vesicle which has been cut off from the outer layer of cells covering the surface of the body. The innermost wall, **Visual organs of snail**

which is now highly specialised as a layer of visual sensory cells, is known as the **Retina.**

Even with an eye of this advanced type it is very unlikely that the snail can perceive objects about it, although it has been stated that some molluscs do recognise form.

The most complicated eye in the Mollusca is found in the scallop, but here there is no head and the eyes are situated on the margins of the fleshy *mantle* which lines the shell valves, and instead of two eyes there are perhaps 40 to 100. This is the usual position in the bivalve mollusca for nerve endings sensitive to light waves.

The Arthropod group of animals (Insects, Crustacea, Spiders and Scorpions, etc.) stands out very distinctly in regard to vision, for not only are eyes present which are extremely sensitive and can certainly perceive the form of objects (and probably colour), but a type of eye is developed which is of a structure altogether different from that of vertebrate animals, and indeed from all other invertebrates.

Two types of eyes occur in this group, and in some cases both are present at the same time. They are known as **Ocelli** and **Compound Eyes,** and it is the latter kind which is so characteristic of the Arthropoda.

The compound eye (crayfish) The Crayfish possesses two compound eyes (see Fig. 163). They are large and easily seen, and each is borne on a long stalk at the anterior end of the head. The eye stalks are capable of movement in different directions. The surface of the eye is convex and black in colour. If examined with a hand lens it will be seen that this area is divided up into a number of squares, which are called **Facets.** These divisions are in the transparent external layer or Cornea which covers the eye, but they correspond to a similar division of the lower layers, for the whole eye is really built up of a series of columnar units called **Ommatidia.** The structure of the Ommatidia is complex and not easily made out except in very good microscope sections. The essential thing to notice is that each ommatidium is made up of a number of cells and that these serve two purposes. There is first a little group of sensory cells which are the real receptive structures and are connected by nerve fibres

with the central nervous system. The other cells are either supporting cells or they are specialised to form a column which acts as a lens and focusses the light on the sense cells. The diagram (Fig. 163) illustrates the scheme of things.

This same type of visual organ, the compound eye, is found in the housefly, honey bee and most insects. In the housefly there are upwards of 2000 facets, and of course the same number of ommatidia.

Now the important question arises—How does the compound eye function? In the simple eye a single lens

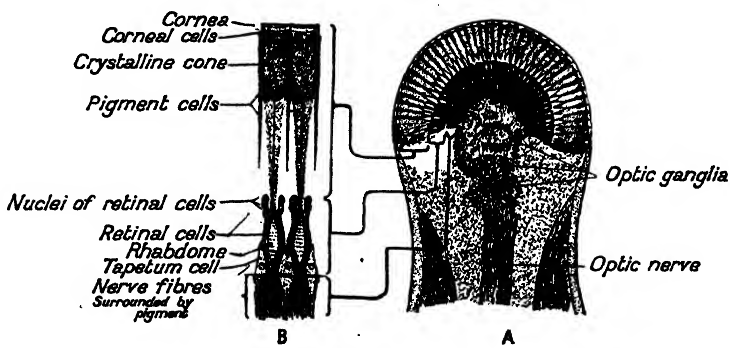


FIG. 163.
A. Longitudinal section through eye of crayfish.
B. Highly magnified view of two ommatidia from *A*.
The Rhabdome surrounded by the retinal cells bears a relation to the latter somewhat similar to that of the rods to rod cells in the vertebrate eye.

throws an image of an object on the retina. Does the lens part of each ommatidium act in the same way? The theory generally accepted to-day (known as the theory of mosaic vision) is that in each ommatidium an image is produced by the light waves from an object or part of an object which is exactly opposite that particular ommatidium. Thus, instead of an image of, say, a pencil being produced in each ommatidium, only a part of it is projected on the sense cells of each ommatidium, and these build up a single image in the eye just as a mosaic is built up of a large number of small stones.

There are, however, two types of compound eye. In one of these (called the **Apposition** eye) which is characteristic

of day-flying insects and of many crustacea, every ommatidium is surrounded with pigment and the sensory cells are close up to the lens apparatus. The sensory cells only receive light rays from the lens apparatus of their own ommatidium. This is simple mosaic vision. In the other type (Fig. 164, *B*), the **Superposition eye,** found in many night-flying insects, the arrangement is such that rays of light from several facets may reach one and the same group of sensory cells. The image is thus brighter but not so 'sharp.'[1]

The crayfish is particularly interesting, because the pigment may be contracted or expanded, so that in bright

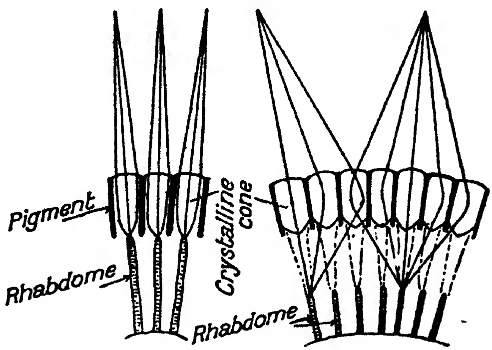


FIG. 164. Diagram illustrating paths of light rays in compound eyes.
A. Apposition eye (day-flying insects.).
B. Superposition eye (crayfish and also night-flying insects).

light the pigment extends deeper round the ommatidia and the eye functions as an apposition eye, whilst under conditions of darkness the pigment is confined to the upper ends of the ommatidia and the eye is a typical superposition eye.[2] A superposition eye makes the best use of feeble light. The compound eye structure appears to be adapted particularly for the perception of movement of small objects.

But it must not be thought that the sense of sight is merely a matter of the sense organs. There are two com-

[1] Very distinct minute photographs of objects have been taken using the eye of a beetle as a lens. This shows that the compound eye of an insect produces a single image, and that the image is more distinct than is often believed.

[2] This is also possible in some insects.

pound eyes in the crayfish, the bee, etc., and there are two eyes in the vertebrates. In many cases the image actually 'perceived' by one of the eyes must be different from that seen by the other (the chameleon, for example, can direct one eye forwards and one backwards). In man and the higher vertebrates the eyes are arranged close together, and so controlled by muscles that the same image falls on the retina in each eye (see below). In any case, however, the actual sense of sight depends not only on the working of the sense organs at the surface of the body, but on the physiological and psychical action of the central nervous system.

Ocelli of insects

In the housefly and in many other insects there are simple eyes or ocelli on the top of the head which aid the

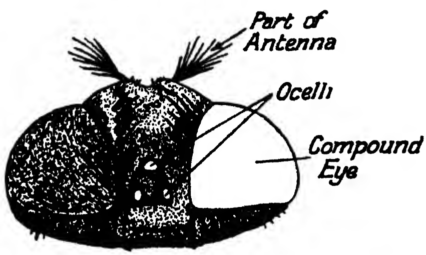


FIG. 165.—View of head of housefly from above, showing ocelli.

others. These are the only kind of eyes present in the caterpillar stage of the butterfly. These eyes are much more like the eyes of the snail and the vertebrate eyes. They have only one lens. It is difficult to determine in the insects whether the function of the two kinds of eyes is different. It has been suggested, however, that the compound eyes are for the distinct perception of objects and their form, and also of movement, whilst the ocelli are more sensitive to slight changes in the intensity of the light or serve this purpose alone when compound eyes are not developed. They do not form images.

Vertebrate eye

There is a close similarity in the structure of the eyes in all the vertebrate groups, and therefore we may as well take the **human eye** for our example, since its structure and functions are best known. The human eye is a globular

structure which rests in a protective socket or cavity of bone called the **Orbit.** In front, the surface of the eye is protected by two folds of skin, the eyelids, which are in a way continuous, for a delicate layer of cells lining the lids is continued over the front of the eyeball. This thin layer is known as the **Conjunctiva.** A 'bloodshot' eye is generally due to inflammation of the conjunctiva—in other words its blood vessels are gorged with blood. The eyelids bear protective **Eyelashes**, and a series of small glands open along the margins. (A sty is produced through the blocking of the duct of one of these.) There is another and larger gland, the **Lachrymal Gland,** which is situated to the outside (side away from the nose) and in the upper part of the orbit. This secretes a watery fluid, the tears, the function of which is to remove dust, etc., from the front of the eyeball. The tear gland also pours out its secretion under other conditions—crying, laughing, coughing, etc.

The wall of the eyeball (see Fig. 166) consists of three layers, but only one of these extends in front, and all of them are perforated at the back to allow the optic nerve to pass out. The outermost coat is known as the **Sclerotic.** This is a strong protective layer, which is rather opaque and is made up of fibrous connective tissue. The 'white' of the eye is the part of the sclerotic which can be seen from the front. The sclerotic is continued in front of the eye as a transparent part called the **Cornea.** The next underlying layer is the **Choroid.** This is thin and quite dark in colour. It contains a network of blood vessels which supply blood to the eye, and especially to the innermost layer. In front the choroid is missing. An extension of it, which forms the margin of the front aperture, is visible through the cornea. It is coloured differently from the rest and is the part which gives the colour—blue or brown or grey—to our eyes. It is known as the **Iris.** The actual opening surrounded by the iris is known as the **Pupil.** This aperture (which looks like a black disc in the human eye and a slit in the cat's eye when the animal is in the sun) can be increased or diminished in size, because the iris contains muscle fibres and is capable of contraction. The

alteration of the width of the pupil is, however, not so extensive in the human eye as in the cat or the owl.

Just within the iris is the **Lens,** a perfectly glass-clear biconvex mass which is not hard, however, but capable of slight alterations in shape. It is suspended by a sheet of tissue, the **Suspensory Ligament,** which extends from the lens margin to the choroid coat. At the point of attachment to the latter, the choroid is thickened and forms a

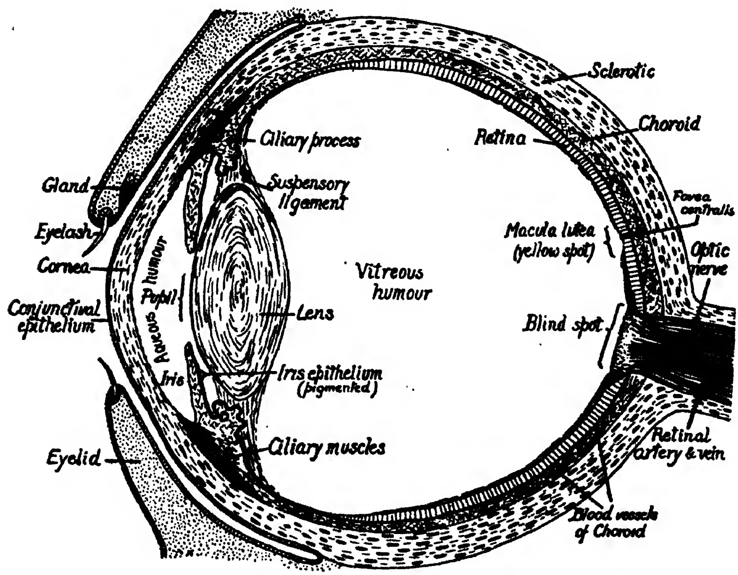


FIG. 166.—Diagrammatic vertical section through human eye.

series of little processes—the **Ciliary Processes.** From here to the sclerotic coat (see Fig. 166) runs a series of muscle fibres (the **Ciliary Muscle**), which are attached to the sclerotic just where it merges into the cornea. The function of this muscle is described below. The innermost coat of the eye, the **Retina,** is the actual sensory structure. This layer is also missing in front, so that it has more the form of a cup. From the retina a large nerve, the optic nerve, runs to the brain. It really arises on the surface of the retina facing the lens, and so it has to perforate the retina to get out. It also perforates the choroid and sclerotic

coats. The cavity of the retinal cup is not a mere empty space, nor is there an actual empty space in front of the lens between it and the cornea. Both spaces are filled with a clear substance, but with a difference in consistency. The space between lens and cornea is filled with a liquid (the **Aqueous Humour**), whilst the space enclosed by the retina contains a rather gelatinous substance (the **Vitreous Humour**).

In some vertebrates, including some of the carnivorous mammals, like the cat, etc., a thin layer of metallic substance is produced between the choroid and the retina. The result is a reflecting layer, which is efficient enough to make the eyes appear to be shining when they are looked into at night and there is a source of light behind or in front of the observer. This accounts for the weird aspect when an animal possessing this layer in the eye approaches a campfire or faces a motor car with head lamps shining. There is, of course, no light produced in the eye at all.

It may be pointed out here that no animals '*can see in the dark.*' The eye is an organ for the reception of light waves from without. Some animals can see when there is very little light—have very sensitive retinas—just as some people can see better in a dim light than others. Very often, too, people forget that many nocturnal animals with extremely sensitive eyes have also the aid of a very keen sense of smell or touch.

How the vertebrate eye functions

Physiologically the eye consists of two parts, a retinal layer of sense cells specialised for the perception of light waves and an apparatus for directing light on the retina and focussing a sharp picture or image of external objects there. The latter work is carried out by the lens and its associated muscles together with the iris. The structures are arranged and function very similarly to a camera, where the lens must focus a sharp picture on the plate or film. The plate or film may be compared with the retina. Now it is known almost to everyone in these days of cheap hand cameras, that the image which the lens throws on the back of the camera is upside down, and that in order to make this image sharp and distinct you move the lens further away

from or nearer to the plate; the former for near objects and the latter for distant objects.

Accommodation. It is just as necessary to have objects focussed sharply and distinctly on the sensory cells of the retina if we want to see distinctly, as it is to have a picture focussed sharply on the film in the camera. Now the eye might do this in the same way, by causing the lens to move further away from the retina for near objects and to approach it for distant objects. This is not the way focussing takes place in man, though curiously enough it is exactly in this way that focussing takes place in bony fishes (see Fig. 167), and probably in the amphibia and some reptiles.

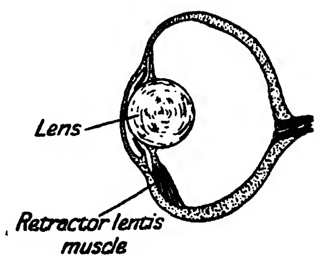


FIG. 167.—Diagram of vertical section through the eye of a bony fish, showing spherical lens and muscle for changing its position (accommodation, see text). Other details are not shown.

We have seen above that the more convex a lens is, the closer the object and focussed image, and we could focus near objects with a camera set up for distant objects if we changed the lens, but did not alter its position otherwise in regard to the plate. Something very similar takes place in the human eye. By the contraction of the ciliary muscle (see above) the margin of the choroid is brought nearer to the lens. This means that the lens is more loosely held by its supporting ligament. Now the lens is not hard like glass, but is elastic, and when the supporting ligament is loosened as above, the lens becomes more convex. Thus it is ready to focus nearer objects on the retina. The nerve control of the ciliary muscle is so delicate that in the normal eye the convexity of the lens can be adjusted for objects at all distances. This is the way in which objects are focussed on the sense cells. The action of so doing is known as

Accommodation.[1] Everyone knows that there are some people who cannot accommodate properly. Old people frequently find it impossible to do so. In these cases it is either impossible to see objects distinctly or else it is achieved with a great strain which is tiring and unhealthy. Some people find it difficult to focus near objects—print when reading—others find it difficult to focus distant objects. The former are said to be long sighted, the latter short sighted. The inability to focus objects sharply may be due either to the shape of the eyeball or to the lens losing some of its elasticity which makes it unable to focus close objects. Fortunately we can correct matters by putting an extra lens—a glass one (spectacles)—in front of the eye. A long-sighted person will need a convex lens, whilst one who cannot see objects distinctly unless they are very close will need a concave lens. (Compare this with the camera experiments tried above.)

The normal human eye is so adjusted that parallel rays of light which enter the eye are focussed sharply on the retina. This really means that the eye is arranged to focus distant objects, and in practice, like most cameras, 'distant' objects mean those beyond 30 feet. To see clearly objects which are nearer to the eye therefore requires some effort—the muscular effort of accommodation.

We have referred above to defects which cause a difficulty in focussing near or distant objects sharply on the retina. There is another not uncommon defect known as Astigmatism, which is not so clearly recognised by the sufferer. It is due to an abnormality in one or more of the surfaces of the lens or cornea which results from their not being sections of perfect spheres. To take an example, the curvature of the

[1] It must be remembered that accommodation takes place in different ways in almost each vertebrate group. Apparently the dogfishes, rays and sharks cannot focus objects at all. In the bony fishes and Amphibia the lens is moved as we have noted above (see page 305), whilst in reptiles, birds and mammals the shape of the lens is altered. This, however, is not the only difference, because the actual mechanism for moving the lens is not the same in the Amphibia as in the fishes, nor is the mechanism for changing the shape of the lens in mammals the same as that in reptiles and birds. Perhaps this is a small detail, but it is too common to find text-books describing the eye of the frog or dogfish as if they were exactly the same as the human eye.

surface of the earth on a meridian running from one pole to the other is not the same as that on the equator. Such a condition in the eye makes it difficult to focus all points of a flat surface at the same time.

Structure of retina

The retina in vertebrate animals consists not only of a layer of receptory sensory cells, but of several layers of neurones (nerve cell units, see page 264). The curious thing is that the sensory cells are situated at the back, *away* from the light, and the nerve fibres collect on the

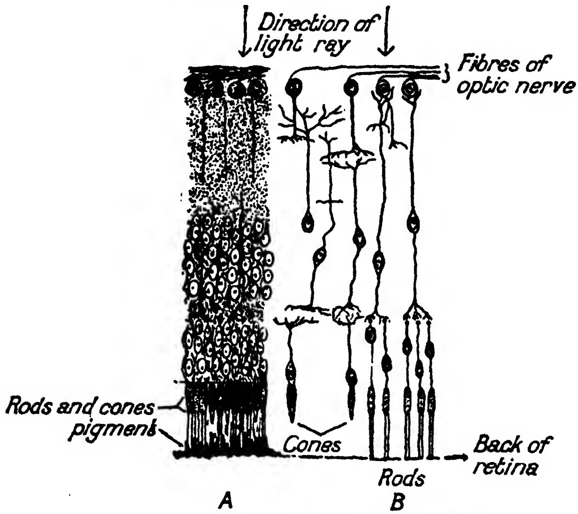


FIG. 168.—The structure of the vertebrate retina.
A. Appearance of retina in an ordinary good section.
B. Diagram illustrating details of retinal structure as discovered by the use of special technique.

surface of the retina nearest the lens. This means that rays of light must pass through the thickness of the retina before reaching the sensory cells, and also that the optic nerve has to penetrate the retina on its way to the brain (see Fig. 168).

Where the optic nerve tunnels through the retina the sensory cells, etc., are of course missing, and consequently there is a spot in each retina where vision is impossible. This is known as the **Blind Spot.** Normally it is not noticed, because the eyes are always moving, and in any case the part of a view which happens to be focussed on the blind spot of one eye will be on some other part of the

other eye. (For method of demonstrating Blind Spot, see end of chapter.)

If an ordinary section of the retina of the frog's eye or rabbit's eye be examined, the structure will be something like that depicted in Fig. 168, *A*. The row of sense cells will be distinctly seen, and it will be noted that they only occupy about $\frac{1}{8}$ the thickness of the retina. The rest of the retina looks like an indistinct mass of fibres and cells which could roughly be divided into about six layers. Careful investigation and special technique has enabled us to discover the connections within this part. They are somewhat as in the diagram, Fig. 168, *B*. It will be seen that the sense cells of the eye are not connected directly with the brain, but that there is a series of interlocking units of the nervous system—the neurones. The sense cells are of two kinds and lie against a layer of pigment cells next to the choroid. Some of the sense cells bear rod-like terminations, others have cones. It is probable that the functions of the two types are different, and it has been suggested that the **cones** alone are capable of the perception of colour, whilst the **rods** are only sensitive to different intensities of light and are the special apparatus for vision in dim light. Probably this is not altogether correct. The rods have a purple-red colour during life due to a pigment known as **Visual Purple.** It is very likely that this substance plays an important part in the perception of light rays—at least by the rods. The colour is bleached by light, and the substance is not usually seen in preparations or dissections.

We have seen that part of the retina, the blind spot, has no sensory cells. There is another small region where all the retinal layers, except that of the sense cells, have been thinned out, and cones only are present in the sense cell layer. This is the most sensitive part of the retina. It is known as the **Fovea Centralis,** and is the centre of a region which, because of a slight yellow tint, is called the **Yellow Spot.** In other parts of the yellow spot both rods and cones are present, but the cones are greatly in excess of the rods. Normally the eyes are constantly being moved

so that the object which is being most clearly observed is focussed on the yellow spot.

Many theories have been put forward to explain the perception of colour, which is the result of light of different wave lengths falling upon the sensory cells of the retina. We know that light is propagated in the form of waves and that vibrations greater than a certain wave length are not perceived by the retina at all. As the wave length decreases a point is reached where the rays are perceived as red light, and from this point shortening of the wave length results in the change of colour from red through orange, yellow, blue, indigo and violet until we again reach a point beyond which the eye is not sensitive. We know there are waves of light of shorter lengths than those causing the sensation of violet. Furthermore these rays are very effective—indeed often destructive—yet they may not be perceived at all by the retinal cells. The retina in a way is like a wireless receiving set which is in tune with electric waves between 300 and 700 metres. We know that there are other waves, but our set will not receive them. If our set is selective enough, we may listen only to waves of, say, 350 metres length, and we hear possibly a band or someone speaking. If we hear, however, two stations at once, or waves of 350 metres and waves of 400, the effect may be a mixing up of two voices or a more horrid noise if we hear two orchestras. **Colour vision**

If light of only one wave length is thrown on the retina and it is a wave length that is perceived by the sense cells, we get the sense of a pure colour. If rays of two different wave lengths are thrown together, we may get a mixture—thus yellow and blue gives green—or we may get the sensation of white, as when pure red and blue green lights are mixed or green and violet, or when the rays visible are all of the different lengths, as in the light from the sun, or an electric arc, etc. Two colours which give white when mixed are known as complementary colours. It will be noticed that it is colours due to light of *similar* wave length that give a mixed tint when both are present, whilst complementary colours are always of very different wave length.

It would take too much space to relate the theories of colour vision, and, whilst interesting, there is a good deal of evidence which makes it probable that most of these theories are untenable.[1] It is necessary, however, to notice a few of the interesting phenomena of colour vision.

After-images

If we close the eyes for a short time and then stare at a brightly illuminated object, such as the filament of an electric light, for a few seconds and again close the eyes, we see the image remaining. This is a so-called after-image, and its colours will probably be somewhat similar to those actually seen with the eyes open, that is, the image is a positive one. An image thrown on the sensory cells of the retina evidently provokes an effect which endures for a brief period after the image has disappeared. It is due to this that cinematograph pictures appear one continuous image and not a series of separate pictures with a very brief dark interval between them. Yet only sixteen pictures are shown in a second.

Stare fixedly for twenty seconds at a well-illuminated white object on a black background (a piece of paper will do) and then look at a sheet of grey paper or dull white background. The white object will be seen as a black object on a white background. This is a negative after-image. Try the same thing, using first a bright red object and then looking at the grey background. It will be seen that the after-image of coloured objects appears in the complementary colour. A large number of experiments with colour have been devised, details of which are to be obtained from special works on the subject.

Colour blindness

It can easily be seen that some people have not the normal power of distinguishing light of different wave lengths, and consequently their perception of colour is limited. Very often this defect is not realised until experiments are made, and consequently there is a danger that such people may become ships' officers or railway men, where, for example, it is highly necessary to distinguish red and green signal lights. Elaborate tests are now made for this purpose in all civilised countries. Colour-blind people

[1] It is stated that there are no less than eighty theories already.

fall into different grades. In one of these, for example, all the wave lengths normally giving the sensations of red, orange, yellow and green, produce only a perception of yellow of different shades, whilst blue-green is grey, and blue, violet and purple are blue. Thus it is difficult for such people to distinguish a green light. Another grade includes people who can have three colour sensations of the spectrum—red, green and violet. They confuse the orange and yellow colours with red and green.

From the above it might be concluded that colour vision had gradually evolved, and that just as there are different grades amongst people, so it is very probable that the lower animals distinguish fewer wave lengths, and possibly do not perceive colour at all. Many experiments have been made to determine whether bees (which, of course, visit differently coloured flowers) distinguish colour. The method adopted has been to place little saucers of honey on squares of coloured paper. A saucer of honey is kept on one colour for a time, whilst similar saucers without honey are laid on squares of other colours. After the bees have become used to the arrangement and visit the honey saucer directly and in numbers, the position of the honey saucer is changed to a square of another colour, and note is then taken of the direction followed by the bees when they return. The experiment is not so easy as it sounds, and many controls have to be made. The evidence is, however, fairly certain that insects distinguish the different colours of the spectrum although the range perceived varies in different species. Some insects can in fact appreciate the ultra violet to a remarkable extent.

Whilst experiments like the above are an indirect way of getting at the action of the eyes of lower animals, we must not lose sight of the fact that colour is found in the animal world in a great many different groups. It is generally supposed that these colours, at least in many cases, are not accidents, but are of some use to their possessors. This postulates that the colours can be recognised by other animals. In fact, the theories of mimicry depend in particular upon a rather exact perception of colour by the

birds. Vision, however, is unquestionably well developed in this group. A more interesting point is whether fish are able to distinguish the bright colours of some sea slugs which they are supposed to avoid.

Binocular vision. If a piece of glass with an ink spot on it be held up at arm's length about six feet in front of a window divided by a cross bar, we shall notice that the ink spot (Fig. 169, I., *i.s.*) appears double when the cross bar (*c.b.*) is focussed sharply. If the ink spot be focussed (Fig. 169, II.), the cross bar on the window will appear double. The explanation is, that when we focus points at varying distances, accommodation is not only taking place, but the two eyes are directed at the point focussed in such a way that the image falls on corresponding parts of *each* retina. (In Fig. I. the image of the cross bar *A* falls on corresponding parts of each retina. In Fig. II. it is the image of the inkspot *A'* which falls on corresponding places in each retina.) This implies that the two eyes converge, and the degree of convergence depends upon the distance of the object. The movements of the eyeballs must be extremely delicate and balanced, and this is the work of the six eye muscles. The reason of the doubling of the cross bar and the ink spot in the experiment is explained by the illustration (Fig. 169). It is due to the images of the object not specially focussed falling on different places on the two retinas, and what each eye sees is recorded separately in the brain.

Perform the experiment again, and whilst looking at the ink spot (Fig. 169, II.) cover up one eye. It will be seen that one of the window cross bars (of the double image) disappears and that it is the one corresponding to the eye covered. Now fix the eyes on the window cross bar and again cover one eye whilst looking at the window. It will be seen that one of the ink spots visible on the glass disappears, but it is the opposite one to the eye covered.

But it will be asked why it is that the two images *AA* and *A'A'* give only one sensation in the brain, whilst the two images *BB* and *B'B'* give two. Experiment shows that the right side of the retina of one eye corresponds to the right side of the retina of the other. Now the spots

BB and *B'B'* are on the left side of one retina and the right side of the other. Thus we may say that when the images of an object fall on the same sides of the two retinas we have a single sensation. When they fall on opposite sides they appear double.

The same effect as the above is obtained if we look at a black spot on a paper with both eyes and then prod one eye slightly with a finger. We direct it to one side and the spot appears double.

Although we do not as a rule realise that each eye is receiving its own image of an object, it is supposed that the

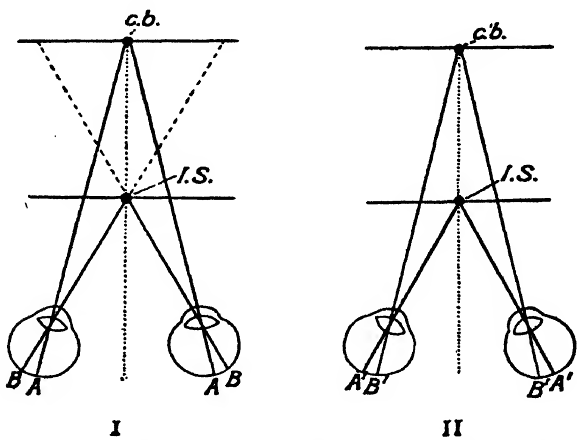


FIG. 169.—Diagram illustrating binocular vision (see text for explanation).

action of the eyeball muscles in directing each eye so that the image of an observed spot shall fall on the Fovea centralis is estimated by the muscle sense organs, and that as a result we form judgments of the distance of the object and we see views in perspective. The estimation of distance and the consciousness of perspective are, however, not due entirely to binocular vision, because we can still be conscious of perspective if we close one eye. The estimation of distance is to a great extent dependent on the muscle sense perceptions aroused when the eye is focussed, that is, by changes in the ciliary muscle and also on our interpretations of mathematical perspective—parallel lines like railway lines which run away from us appear to

converge in the distance. If we want to produce the impression of distance in a picture we make 'parallel' lines converge.

Estimation of distance by lower animals

In many of the lower animals there is no possibility of binocular vision aiding in the estimation of distance. The eyes of almost all fishes and most lower vertebrates cannot be so directed at an object that the image falls upon corresponding points of the two retinas. A chameleon may have one eye directed at a fly and the other one directed elsewhere, and yet its stroke will be made unerringly. But this is possibly exceptional, and the estimation of distances may be very poor in the fishes and amphibia, although this is contradicted by the smart way in which some of them capture flies.

Stereoscopic vision

In the insects with compound eyes binocular vision is possible, but there is no possibility of directing the eyes at all. Possibly the estimation of distance, if it exists, depends upon the level of the plane of the image in the ommatidia (see page 298).

The fact that, if we observe simultaneously by means of **a stereoscope** two pictures of an object taken from slightly different view points, we obtain a sensation of perspective depends also upon binocular vision. Normally, when we look at a scene, each eye receives a slightly different image, because of the difference in position. If, therefore, instead of taking one picture of a scene with a camera (which is really the image as seen with one eye), we take two pictures by means of two lenses just the right distance and angle apart, and can contrive to present these simultaneously so that the left eye gets the left-eyed image and the right eye the right-eyed image, we shall obtain the effect of looking at the object or scene in nature, that is, the effect of distance, depth. There is more than one device for presenting the pictures to the two eyes, but all are stereoscopes.

Optical illusions

The fact that distance and size are a matter of judgment depending upon the movements of delicate muscles in the eye, and of our estimation of the perspective in images, explains how the judgment may be disturbed so that the

eyes give totally incorrect estimations. In the figure the lines *A* and *B* are exactly the same length, but *A* appears much longer than *B*. In the next figure the vertical lines appear to be at slight angles to each other, whereas they are exactly parallel. Copy the drawing, making the parallel lines first. Entirely satisfactory explanations of these illusions have, however, not yet been given.

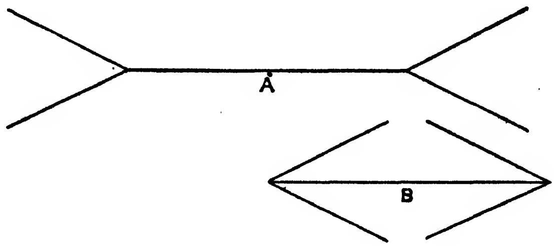


FIG. 186A.

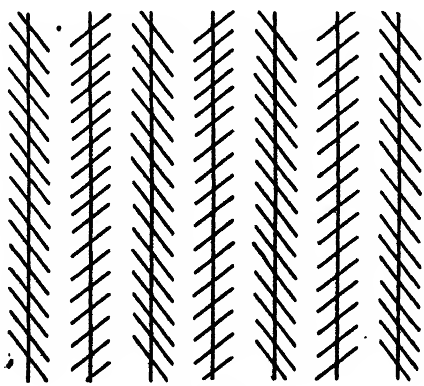


FIG. 186B.

Practical Work on sense organs

I. *Coelenterata.* Examine specimens of *Obelia* medusae and note ocelli and statocysts depicted in Fig. 154.

II. The antennae of insects provide excellent objects for the observation of touch and olfactory sense organs. The antennae of male and female butterflies, and particularly worker and drone bees, should be first treated with solution of caustic potash (2%) and then washed with water. The specimens should now be dehydrated in alcohol and mounted in canada balsam (see page 92). On the antennae of worker bees there is a perfect forest of sensory hairs

which project from little pits. At the terminal end of the antennae are cone-like hollow projections which are regarded as olfactory organs. Other types are present, but require careful preparation. Touch corpuscles may be observed in a similar manner on the tip of the proboscis of the cabbage white butterfly.

III. The statocyst of the crayfish should be examined as an example of an organ of orientation. Dissect out the sac and examine under the microscope (see description in text).

III*a*. Mount a small specimen of Mysis (or more particularly the end of the abdomen) and examine under microscope for Statocysts—see page 289. Mysis can be obtained living or preserved from the Marine Biological Station, Plymouth.

IV. Remove the wings from a field grasshopper (note distinguishing *short* antenna) preserved in alcohol, and note the tympanic membrane of the auditory organs above the last legs on the sides of the thorax. If a surrounding piece of the thorax be removed and mounted after appropriate treatment in canada balsam, further details can be made out, and possibly the auditory nerve will be seen passing to the membrane. A small spiracle opens close to one side of the organ. If the specimen is a male, look for sound-producing structures—a series of teeth on the inner side of the joint of the hind legs and a strongly ridged vein on the fore wings.

V. Examine external features of compound eyes of bee or other insect with hand lens. The cornea can be removed from surface of eyes treated with caustic potash and examined with compound microscope when mounted in canada balsam. Note bristles for protection. A purchased section through the eye of an insect should be examined. Probably it will not be good—it is difficult to make sections through the hard chitin. It should, however, show the ommatidia of which the eye is built.

VI. Examine the pigmented mantle edges of a live mussel or cockle and try effect of throwing a beam of light or a shadow on this part.

VII. Note the effect of a beam of light falling on an earthworm. The specimen should be in a dark room illuminated with red light (photographic lamp). Note that the anterior end is more sensitive than the middle or tail end.

VIII. Note the effect of light upon Daphnids in an aquarium tank. The best method is to place a little aquarium water containing Daphnids in a small rectangular jar and submit them to diffuse light in a dark room. Use beam of light and ground or opal glass. When Daphnids are evenly distributed throw a strong beam of light on the jar. The Daphnids sink and also move away from source of light. Reduction in light to moderate diffuse condition should cause the Daphnids to rise and move towards the light. It will be noted in any case that in collections of Daphnia in aquarium tanks there are optimum light conditions where the animals collect. Make comparisons with moths attracted by candle light, or place a few bees in an open jar, the opening of which is directed away from a source of light in a dark room. Note that the animals keep at the illuminated closed end.

IX. *Cutaneous Sense Organs.*—Sections through the sense corpuscles of human skin may be purchased. An excellent method of demonstrating the terminations of nerves in skin receptors is the following. Take a small piece of conjunctiva from a *fresh* ox or calf eye (the region just surrounding the cornea is best) and spread it on a microscope slide with inner surface uppermost. Drop upon it a little 1 per 1000 methylene blue solution in water. Watch carefully under the *low* power of a microscope. Gradually the nerve fibres will come into view (after 10 minutes or so). When they appear, cover the preparation with cover glass and examine with high power. The nerve fibres will be seen to terminate in sense corpuscles. The experiment should be repeated if it does not succeed. Sometimes one or two attempts are necessary before a successful preparation appears.

IX*a*. The disposition of the human cutaneous organs for heat and cold and touch may be discovered by touching

lightly the surface of the back of hand or arm with a pointed metal object (rather rounded point) which has been warmed to about 50° C. for the heat spots and made cool for the cold spots. Touch the skin successively here and there and note the difference in the sensation. For the touch spots finer points are necessary—a hog's bristle or a finely drawn-out piece of glass will do. Mount the pricker in a piece of wood. Touch spots are too close together to recognise on the tips of the fingers. Since the pressure spots are most often at the base of hairs it is best to cut them off, marking such places with spots. Another person may aid in applying the stimulus.

X. Make a dissection of the eye of a cow, which should be easily obtained from an abattoir. The description given above should serve as a guide. Note also the eye muscles attached to sclerotic. They are six in number, and serve to keep the eye in place and to turn it in any direction. Divide another specimen into halves with a sharp razor, taking a plane through middle of cornea in front and through optic nerve at back. If a fresh eye can be obtained, cut out a small window at the back (scissors). Place a little cigarette paper over the window and hold a burning candle in front of the eye. The image of the flame should appear sharply and inverted on the paper. (Experiment from L. Hill's *Human Physiology*.)

XI. Take a small camera, the back of which can be removed and replaced with a ground glass plate (if a camera having a ground glass for focussing is obtainable so much the better), and note the inverted image of objects focussed. Move the lens towards, and away from, the ground glass, and note that distant objects are focussed when the lens is brought near the ground glass. Focus an object 12 feet away and then bring a small bi-convex lens in front of the camera lens. This will bring objects into focus which are nearer to the camera. Try the effect of a concave lens placed in a similar position.

XII. If an ophthalmoscope is obtainable, examine the human eye with it. The instrument consists essentially of a mirror with a hole in the middle of it. The principle of

Its action is as follows. If we direct a light through the pupil into the eye it lights up the retina, and some of the rays are reflected back. Since, however, they are reflected back along the same line as they entered, it is impossible to see them unless the source of illumination and the observer's eye are at the same place This is achieved by the ophthalmoscope. (The principle of its use can be easily

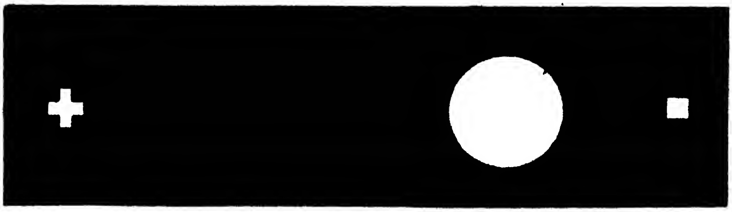


FIG. 170.—Diagram to aid in observation of blind spot (see text).

demonstrated by looking with it at a piece of printed paper stuck inside a cigar box on the side opposite a small hole—both hole and paper being on the narrow ends.)

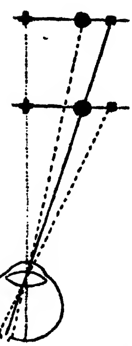


FIG. 171.—Diagram illustrating what happens in blind-spot experiment.

XIII. The capillaries of the retina can be seen if the observer looks at the window through a small pin-hole in a card and gives the card a rotary movement as he does so. A little practice will enable one to see a shadow network. A much more distinct view of the shadows of the retinal vessels is seen if the observer shuts the left eye and arranges himself so that he looks obliquely across his nose into a distant dark corner of the room. If now an assistant reflects or concentrates a beam of light obliquely from the right on to the front of the eye (this can be done with an electric light and a small pocket lens) and slowly moves the beam, the shadows of the blood vessels stand out quite distinctly.

XIV. To demonstrate the presence of a blind spot (which should have been seen in the dissection of the cow's eye) make two marks on paper, a cross and a black spot, about three inches apart (see Fig. 170). The experiment is

perhaps better with white marks on a black background. Gaze fixedly at the cross with the right eye (the left being closed) and move the paper slowly to and from the face. Somewhere about ten inches from the face the spot (whose presence is for the great part detected although not directly

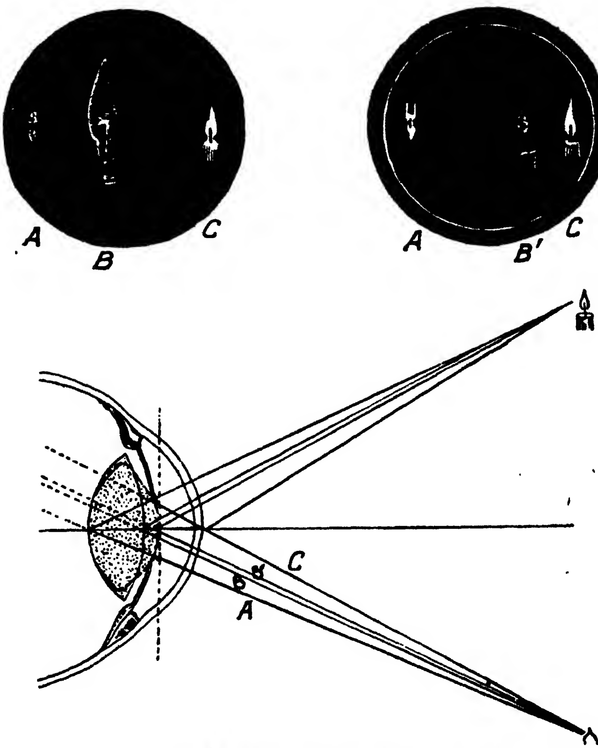


FIG. 172.—Images of candle flame reflected from human eye (see text for explanation).

looked at) will disappear. At this point its image has fallen on the blind spot of the right eye.

XV. It is possible by a simple experiment to show that accommodation takes place in the way described on pages 305, 306. Two persons are necessary, the observer and the observed. They should sit opposite each other and the eyes should be on about the same level. A lighted candle is now placed so that the flame is the same height as the eye and about one foot to the right side of the observer's

head. The assistant looks straight ahead between the candle and the observer and focusses an object some distance away in the room. The candle should now be moved about until an *upright* bright image of the candle is seen at the right edge of the left pupil of the assistant (Fig. 172 (*a*)). It will be seen that there is at the same time a second image at the left side of the pupil (*c*). This is not so distinct and it is inverted, but sharp. There should now be seen a third image between these two (*b*). One must look as it were into the eye to see it as if it were much further back than the first mentioned. It is larger and upright, but not distinct. The first image, the brightest, is the reflection from the outer surface of the cornea, the second is the reflection from the back surface of the lens, and the third is the reflection from the front surface of the lens. Now try and get the assistant, without moving the head or the eye, to look at a point between the candle and the head of the observer (instead of at the distant object). The middle image of the candle should become smaller, and it should move nearer the corneal image. This is due to the front lens surface becoming more convex as the eye is accommodated for the near point. The actual conditions should be imitated by mounting three watch glasses one behind the other and close together on a piece of wood. (Use plasticine.) The two front ones will, of course, have their convex surfaces in the same relative position, whilst the back one will have its concave surface facing the concave surface of the second.

XV

EXCRETION

As we have already seen, the activities which are recognised as characteristic of living things are only sustained by chemical changes in the protoplasm, and these cannot take place without the production of waste.

The body of a living animal might be compared to an extraordinary automobile, which, whilst shedding particles of its substance as a result of wear and tear, replaced automatically and just as gradually the lost parts from its fuel. Accumulation of waste materials resulting from wear and tear (steel particles in the cylinders, for example) would be unsatisfactory even if repair processes took place, and this would apply more immediately if the waste gases from the engine were not led quickly away through the exhaust. Waste matter would interfere with the proper working of the machine. This also applies to the living animal.

Usually in the animal the waste is got rid of as it is formed. In some cases it is stored for a little time and extruded at intervals, and in a few cases it may be stored for longer periods in some modified and non-deleterious condition.[1]

In the widest sense the term excretion in biology might be employed to cover the extrusion from the organism of all unwanted substances—unused and perhaps undigested stuff from the alimentary canal as well as waste material resulting from the chemical changes in the actual substance of the animal itself. Generally, however, the term is restricted to the latter. It would thus include the giving off

[1] Special groups of cells, called urate cells, for storing excreta are commonly found in insects in the neighbourhood of the heart and also in the fat bodies.

of carbon di-oxide (one of the final products resulting from the oxidation processes) as well as non-gaseous products.

But the passage out of carbon di-oxide is usually controlled and effected by special organs, and it is intimately related to the intake of oxygen. It is therefore treated under the term Respiration, and Excretion becomes narrowed down still further to mean the output of non-gaseous waste products, amidst which nitrogenous substances resulting from the breaking down of the proteins play a great part. The substances excreted may in some cases pass out by the skin, by the alimentary canal walls, or even by the respiratory surfaces, but in most cases special organs carry on this work, although the other structures mentioned may act as accessories. Excretion must not be confused with secretion. The term secretion means the production of substances of use to the organism (whether they pass outside it or remain within the body). The formation of gastric juice, pancreatic juice and other ferments is secretion, and so is the production of snake venom in the poison glands of certain snakes, the extrusion of mucus from the snail's foot, or the oil of the sebaceous glands and so on. The excretory organs differ from organs of secretion in another way. They often do not prepare the waste, but only pick it up and conduct it out of the body.

Respiration and excretion

Secretion

Amongst the fluid excretory substances water plays a very prominent part. It is not only a waste product itself, but is a vehicle or carrier for other substances which pass out in solution. Amongst these are lactic acid, fatty acids, mineral salts, etc. The most characteristic substances are, however, the nitrogenous compounds, especially Urea, Uric Acid, Ammonia, and Creatinin.

Excretory substances

Others are Guanine, Trimethylamine oxide, Bile Acids, and some rather special compounds. The Ammonia and Trimethylamine are in particular excreted by fishes and invertebrates. There are also solid nitrogenous excretions, such as the concretions or crystals often found in the cells of the invertebrate excretory organs.

Urea is a most important organic waste substance excreted from the bodies of fishes, Amphibia and mammals. It leaves the body in a dissolved state in the urine. Urea

is a crystalline solid, a compound of Carbon, Hydrogen, Oxygen and Nitrogen—$CO(NH_2)_2$. It is easily broken down, and this may take place through the action of bacteria when urine is exposed to the air. The urea is converted into ammonium carbonate, and this accounts for the ammoniacal smell of stables, etc. Urea is also interesting, because it was the first organic substance to be synthesised in the laboratory from purely inorganic material. Before

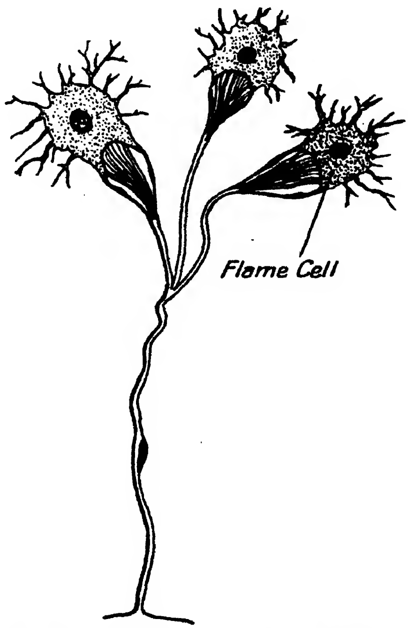


FIG. 173.—Diagram of a branch of excretory system from liver fluke with the terminal flame cells.

this discovery was made in 1828, it was believed that organic compounds could only be made in the living cells of plants and animals.

Uric Acid, which is present with urea, but only in small quantities in the animal groups mentioned above, becomes the chief organic waste stuff in the whitish semi-solid excretions of birds and reptiles. It seems to be correlated with the egg-laying habit of these two groups. Uric Acid is found with other nitrogenous compounds in the excretions of the invertebrates, but much research remains to

be carried out before the chemistry of the lower animals is better understood.

Naturally in the animal kingdom there is a variety of excretory organs, but considering the variety of animal life the number of fundamental types of excretory organs is comparatively small, and the function performed is still more uniform.

In *Hydra*, and the group of Coelenterates to which this animal belongs, there are no definite excretory organs at **Hydra**

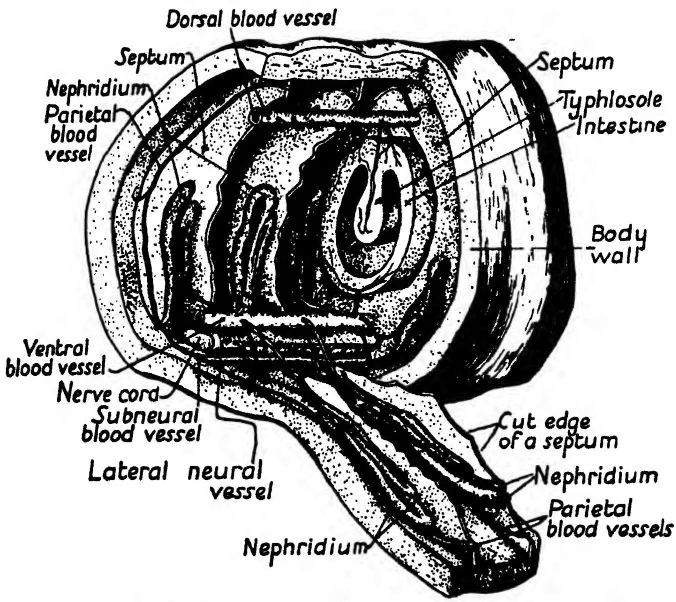


FIG. 174.—Reconstruction of portion of an earthworm (intestinal region) to show relative position of different organs. (After M'Gregor and Calkins.)

all. The cells of which the animal is built are in direct contact with the outer medium, and the body surface is thus the excretory surface. The individual cells get rid of their waste as do Protozoa. As a matter of fact it is most difficult to demonstrate excretion in *Hydra*, and we take its existence more from theory than practice, knowing that waste is universal where there is life.

In the lower worms—the flat worms such as the tapeworm and liver fluke, referred to in Chapter XIX—there is a well-developed and highly characteristic excretory system, **Excretory organs of worms**

which consists of a number of branching canals (their course and arrangement differ in the various species), each of which ends blindly with a single cell. The canal is actually a cavity within cells, but these have no excretory function. It is the end cell alone which removes waste. From this cell a number of flagella project into the tube. The flickering movement of the flagella gave rise to the term '**Flame Cell.**' The flame cell has prolongations of its surface in contact with the surrounding tissue cells, and by its activity water, with waste from the tissues, passes through it to the canal system. The stream eventually reaches an aperture to the exterior. In this excretory system all the essential features are present, for the typical excretory organs of animals are tubes or groups of tubes (see Figs. 63 and 173).

The excretory organs of the earthworm are more obvious than those of the flatworms. They are segmentally arranged, and consist of a pair of tubes in each segment except the first three and the last. They are known as **Nephridia.** Each nephridium appears to the eye as consisting of three loops, but in reality there are loops within these (see Fig. 175), and the character of the tube is not the same throughout. The commencement of each nephridium is a tiny funnel-like expansion situated just in front of the anterior septum of the segment, in which the main coiled part of the organ lies. The funnel, termed the **Nephrostome,** bears cilia, and it is supported by the septum. Following the nephrostome the nephridium is very narrow, then it becomes wider and the walls are well provided with cilia. The wall of this part is also distinguished by its brownish colour. Following this region, the tube becomes still wider and the cells of the wall are glandular (also brown in colour). Lastly, there is a section with a muscular wall, and this is sometimes known as the muscular duct. All the loops are bound together by delicate connective tissue in which there is a network of blood capillaries. Excretion takes place in two ways. A layer of yellow cells (called yellow or chloragogenous cells) covers the alimentary canal, and these take up waste matter (the yellow substance

itself) from the blood. Eventually the yellow cells fall into the body cavity, where they break down and set free their contained granules. These are picked up by the nephrostome and swept down the nephridium. (The cilia of the nephrostomes apparently act as a fine screen or sieve, so that only the smallest particles can leave the coelom in this way.) In addition to this mode of excretion cells of the second and the glandular region of the nephridium also abstract excretory matter from the blood and coelomic fluid and pass it into the lumen of the nephridial tubes, from

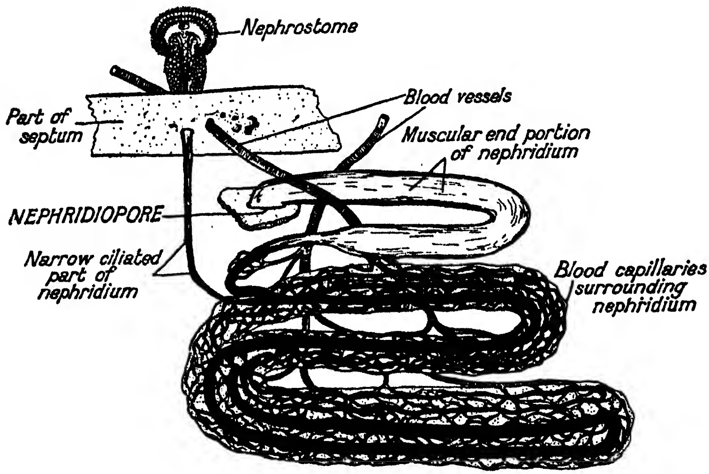


FIG. 175.—Nephridium of an earthworm.

whence it passes to the exterior. These two methods are found in certain other animals, where excretory tubes open into the body cavity at one end and to the exterior at the other. In other cases again the first method has been lost, and the excretory tubules function only in the second way described.

In the Molluscs like the mussel and the snail the excretory organs are again tubes. Sometimes they are very wrongly called kidneys, because the excretory organs of vertebrates are kidneys; and using this line of argument, it would be just as correct to call the contractile vacuoles of Paramecium kidneys. The name should not be used except

Excretory organs of molluscs

for the vertebrate excretory organs. There are only two excretory tubes in the marine mussel and only one in the snail, and they have the form of sacs with spongy walls possessing a very rich blood supply. In every case there is an opening to the exterior and also an internal opening, but there is no large internal body cavity in these animals, and the excretory tubes open into one of the remaining parts of it—the pericardial cavity which encloses the heart. The cells of the walls of the excretory ducts excrete waste substances from the blood, but this is not all, for just as in the earthworm excretory substances are passed from

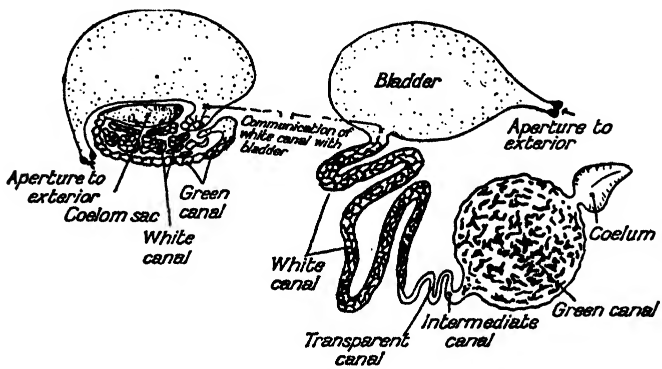


FIG. 176.—The excretory organ of the crayfish (green gland).
A. Schematic section through gland.
B. Schematic view after spreading out the different parts. (After Marchal.)

the body cavity (coelom) down the nephridia to the exterior, so here there is an excretory region which is in the pericardium and covers the auricles of the heart. Substances picked up by the cells of this excretory epithelium (called the pericardial gland) leave the pericardium by way of the excretory ducts.

Excretory organs of crustacea The same kind of mechanism is met with again in the Crustacea, but there are different types of excretory tubes, of which only one pair are present. In the small Daphnids of the pond they are known as **Shell Glands,** and are blind tubes opening near the mouth. In the crayfish they are more complex and scarcely look like tubes at first sight. They are compacted and are situated in the head, one at each side, and open at the base of the antennae. When

dissected out each presents the structure depicted in the illustration (Fig. 176). The internal sac is again one of the remnants of the coelom—the body cavity of the earthworm and of the vertebrates. Both the sac and the tube walls have excretory functions. The whole structure is called the **Green Gland.**

Insects' excretory organs

Although the insects are related to the Crustacea, their excretory organs are rather different. They consist of delicate blind-ending tubules which open into the alimentary canal. They vary in length and in number. In the housefly there are only four, in butterflies usually six. In the cockroach there are sixty or more in six bundles, and in

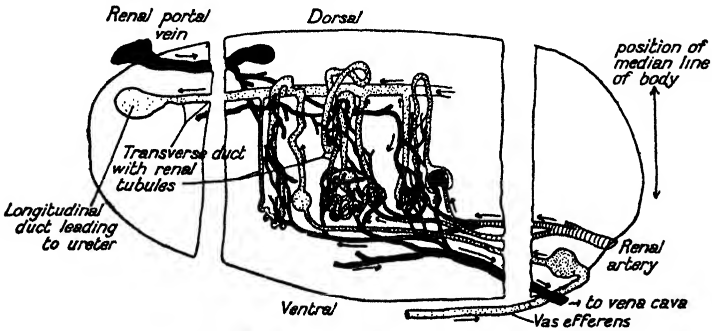


Fig. 177. Diagram showing the relations of the renal tubules and the blood vessels in the kidney of a male frog.
(The sketch is a highly diagrammatic view of a transverse section of the kidney.)

some other insects up to a hundred. The cells of these **Malpighian Tubules,** as they are called, remove waste nitrogenous matter in the form of uric acid, and possibly urea, from the fluids in which they lie (see Figs. 31 and 35).

Excretion in vertebrates

In the vertebrates excretion is almost exclusively carried on by the **Kidneys**—often rather solid looking organs, but in reality masses of tubules which, in the lower vertebrates, open to the body cavity. These openings are lost in the higher vertebrates. The arrangement of the tubules is rather complicated and no attempt at description will be given here, because the diagrams of the frog and rabbit kidneys show the essential features in two examples. Leaving aside accessory functions (the excretory tubules of the male frog are connected up with the reproductive

organs and so also act as channels for the spermatozoa), each excretory tubule consists of a long canal with glandular walls ending internally in a thin-walled enlargement, the **Bowman's capsule,** which has one of its surfaces pushed in by a little network of capillaries (the **Glomerulus**). The whole arrangement is called a Malpighian corpuscle. Networks of blood vessels surround the tubules.

In the frog the blood enters the kidney, not only by renal arteries but by the renal portal vein. In the mammals there is no renal portal vein. The course of the blood is as follows (see Fig. 178). From the renal artery it enters

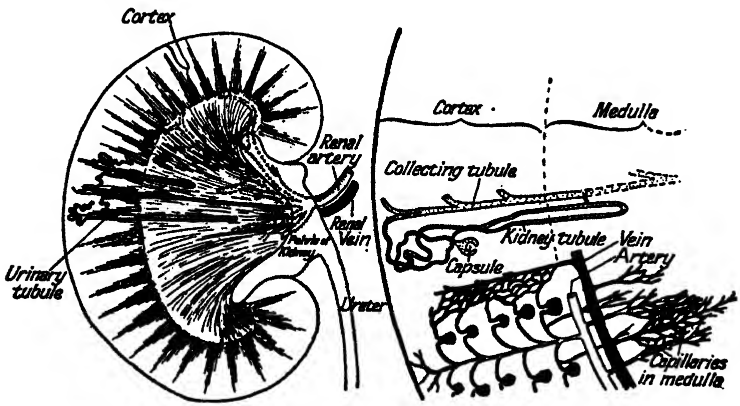


FIG. 178.—Diagram showing path of blood vessels and renal tubules in kidney of mammal.

smaller arterial vessels, and from these, branches go to the Malpighian corpuscles and also to the walls of the tubules. From the glomeruli the blood goes by little efferent vessels to join the other capillaries, which by their repeated junction form the renal vein. In the frog, where some venous blood enters the kidney by the renal portal vein, this blood does not go to the glomeruli, but enters the capillary system surrounding the tubules.

The structure of the kidney is beautiful, and it has been clearly made out. The process of excretion is, however, something much more open to dispute. It is usually supposed that the blood enters the glomeruli under some pressure and that part of it filters through the walls of the

capillaries and through the wall of the capsule into the urinary tubules. This part consists of water, salts, and the urea. (Naturally blood corpuscles and other organic compounds of the blood cannot pass through the blood vessel walls in this way.) Whilst, however, this filtrate is passing along the urinary tubules, a great part of the water is resorbed together with certain other substances and enters the blood which has passed from the glomeruli into the capillaries surrounding the urinary tubules.

In addition to this, the living cells lining the urinary tubules remove other waste substances from the blood, such substances passing through them to the fluid (urine) within the tubule.

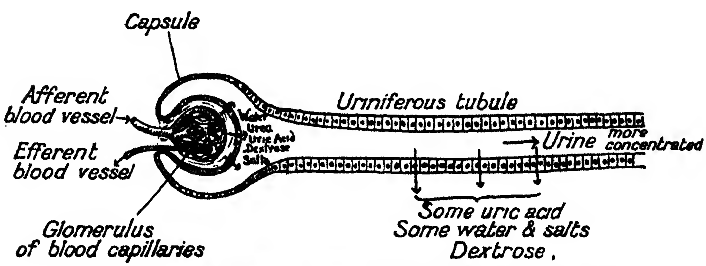


Fig. 179.—Diagram showing process of excretion in *human* kidney tubule. (Note that chemistry of renal excretion varies even in the group Mammalia).

The composition of the urine varies in the different groups of vertebrates, but even within the same group, the mammals for example, one finds that the urine of plant eaters (herbivores) is different from that of the carnivores. The urine of the latter is acid and contains more uric acid than that of herbivorous mammals.

Excretion in birds and reptiles

The greatest difference, however, is met with in the birds and many reptiles (two groups which differ so much in external appearance, but constantly present us with their relationships). In these animals the excretion is not a fluid urine, but a white semi-fluid substance which is quite conspicuous where birds abound (pigeons nesting on buildings, etc.). This whitish excretion comes from the kidneys and probably commences within the tubules as a fluid urine, but on its way to the exterior the water is

resorbed to such an extent that a highly concentrated mass remains, which is largely uric acid.

There are places in the world where countless generations of birds have nested in huge numbers. The result of the accumulated excreta of the birds is a thick deposit rich in nitrogenous matter, and known as guano. So great are the deposits formed in this way on some out of the way islets that companies have been formed to work the deposits as fertilisers for agricultural use.

Before leaving this section, it should be noted that in most cases the excretions leave the animals intermittently. In the higher vertebrates the ducts from the kidneys enter a bag—the bladder—which stores up the urine and allows it to escape at intervals.

Practical work on excretion

I. Notice should be paid to the excretory organs in dissections of the earthworm, mussel, snail, insects (cockroach, Dytiscus or bee), crayfish, dogfish, frog, bird and rabbit. A nephridium should be removed (practice required) from an earthworm which has just been killed (chloroform) and examined in salt solution under a high power of the microscope. The aim of this should be to find the nephrostome and observe the cilia. A hand section of a kidney from a rabbit or sheep should be examined with a hand lens. Procure or make microtome sections of frog's kidney and kidney of mammal—injected kidneys are particularly instructive.

II. Keep some specimens of Daphnia or Cyclops living for a few days in a small dish of water to which very finely divided carmine has been added (pond water containing algae suitable as food is best). Examine with microscope and note presence of carmine, not only in alimentary canal but also in the excretory organ (see Fig. 28). This carmine has passed in soluble form through the alimentary canal walls into the body fluids and eventually has been picked up by the excretory organ.

III. Examine specimens of urea and uric acid. Make the following tests:

Urea. (*a*) Observe solubility in water and crystals formed when solution is evaporated to dryness.

(*b*) Heat urea crystals in dry test-tube until they melt. Note fumes of ammonia are given off. Remove from flame, and when cool add sodium hydrate and a drop of copper sulphate solution. Note the pink 'biuret' colour.

(*c*) (From Ramsden's *Laboratory Directions.*) Add to a little 2% solution of urea a pinch of Soya-bean meal (grind up bean in laboratory) and a little litmus solution. Add barely enough 1% acetic acid to turn the litmus red. Note that in a few minutes the mixture turns blue and becomes strongly alkaline as the urea is changed into ammonium hydrogen carbonate and ammonia.

IV. Demonstration of urea in urine. To about 2 c.c. of urine add the pinch of Soya-bean meal, litmus and acetic acid as in test above and note the same reaction occurs. This is a simple test for urea. Reference should be made to works on Bio-chemistry for details of urine analysis.

V. *Uric Acid.* Examine solubility in water—it does not readily dissolve in boiling water. Add a little sodium carbonate and note its solution (as sodium hydrogen urate).

Murexide Test. Moisten a crystal or two of uric acid with nitric acid (best performed on a microscope slide) and heat gently until it becomes yellowish red. Add a drop of ammonia and note purple colour. Make the same test with a particle of the whitish excreta from the domestic fowl.

XVI

GROWTH AND REPRODUCTION IN MULTICELLULAR ANIMALS

We have already seen that the power of reproducing their kind is a characteristic feature of living animals (see chapter on Protozoa). Each individual comes into existence as the product of a similar organism, it grows to a certain size and then in turn produces a new generation. Although some knowledge of reproduction has been in existence from the earliest times, it was believed, until the work of comparatively modern biologists, that certain animals commonly originated from non-living matter. Frogs and fishes were supposed to arise from mud (whereas they had burrowed into it and remained hibernating or resting through the winter or summer),[1] and worms and insects were generally believed to arise from decomposing matter. The work of Pasteur, Tyndall and others, however, showed that if decomposing matter is sheltered from all possibility of infection and if organisms actually living in it are killed off, no others will arise. Meat properly screened from insects will not be found with fly larvae crawling over it, and it is such larvae which have been mistaken for worms. So far as we know, there is no such thing as **Spontaneous Generation** to-day, and all living organisms have arisen as the result of the power of reproduction.

The Protozoa, as we have seen, consist of a single cell. When this reached its full size it divided into two parts, and these halves continued as two new individuals. This type of reproduction is called **Asexual Reproduction,** when the act of simple fission is not related to anything in the

[1] Such a belief is still held amongst some of the settlers in Australia who live in districts where these animals may not be seen at all during a long summer or a longer dry spell.

nature of a union of two cells or an exchange between two cells. But even in such simple organisms as the Protozoa there appears in most cases to be a limit to this simple division. Frequently we find that before new individuals are produced, the full grown cells meet in pairs and exchange part of their nuclei (Paramecium is an example), or else cells are produced which completely unite in pairs to give rise to new individuals. The exact explanation of such a phenomenon, which is almost universal in both the plant and animal kingdoms, is unknown, although many theories have been put forward. This type of reproduction is known as **Sexual Reproduction,** because generally amongst multicellular animals the cells which unite (germ cells or gametes) are unlike in shape and size, and the individuals which produce them are also different, the two forms being known as male and female. A male animal is one which produces male germ cells (spermatozoa), a female is one which produces female germ cells (ova).. No other definition is required, and, except for the fact just mentioned, the two sexes may be quite alike. This is the case with the starfish, the sea-urchin and many other animals. On the other hand, the two sexes are often very different both in appearance and size.

Asexual reproduction

Now let us turn once again to Asexual Reproduction. It must be obvious that it would not be as simple for multicellular animals, and especially those of complex structure and of dissimilar parts, to reproduce by fission as it is for the Protozoa. The division of a cell into two is not so drastic as the division of a highly organised animal, and, in fact, in multicellular animals simple fission is only found in the lower groups. When the body is unequally divided in asexual reproduction, it is very usual to speak of **Budding** instead of fission. This is exemplified in *Hydra,* where small outgrowths of the body wall soon show a characteristic little column with a mouth and tentacles surrounding it. After a little further growth, the bud, as it is called, is cut off from the parent by constriction of its base, and it leads an independent life. In some forms allied to Hydra the buds remain attached and grow up and produce buds in

their turn. Thus a colony is produced (Fig. 180) in a manner which is not unlike the growth of a branched plant. Even amongst such highly developed animals as the worms, we have asexual reproduction by budding, either by little branches growing out or by new heads developing at intervals, the body then breaking up into separate pieces, each with a head (see Fig. 181).

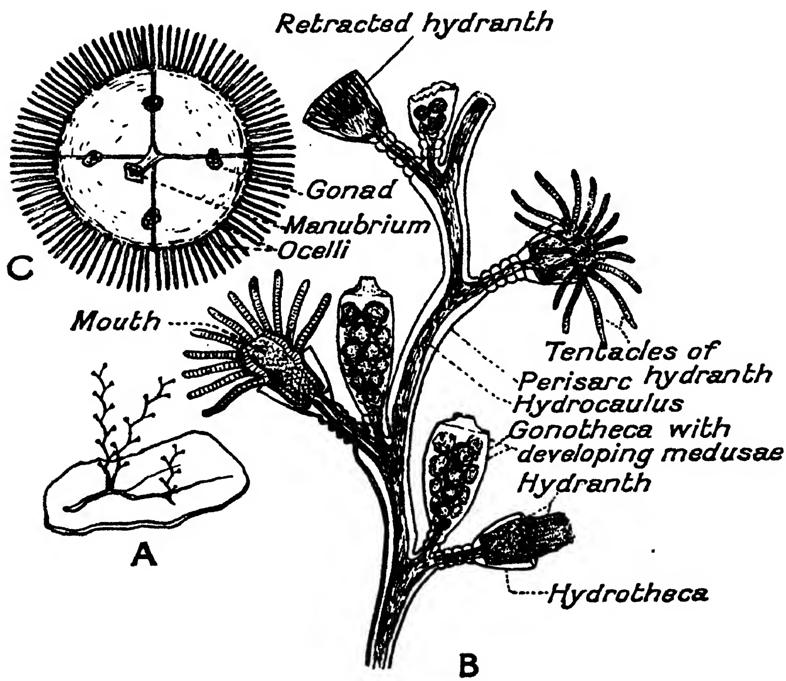


FIG. 180.—*Obelia.*
A. Naked eye view; *B.* Enlarged; *C.* Medusa.

An important distinction must be pointed out here between budding and fission. A Hydra may go on giving off buds for a season, but eventually it dies. But when an animal divides into two it vanishes by the creation out of itself of two descendants, and there is no death as we normally understand it. The act of fission in such cases has in some way rejuvenated each of the parts, for each goes on with the renewed activity of a young organism.

In some of the higher animals where fission or budding

does not occur, and also in others like Hydra and certain worms where it is normally a form of reproduction, it is found that the individual can replace lost parts. It is well known, for example, that lizards often throw off their tails when in danger and afterwards grow new ones. Regeneration

This power of **Regeneration** is so great in some animals that it almost becomes a form of asexual reproduction like fission. Thus if a *Hydra* be cut into two or even into small parts, each piece, so long as it contains a fragment of both ectoderm and endoderm, will regenerate what is missing, and a number of new Hydras will arise. Fishermen off the coasts of England who capture starfish in their nets often tear them into pieces (knowing they are pests on the oyster beds and on other shellfish). This treatment probably only increases the number of starfish, because one arm and a piece of the middle disc region will regenerate the other

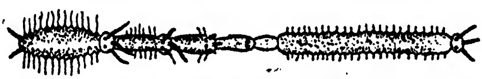


FIG. 181.—*Autolytus.* Formation of three new individuals by budding.

arms. The crayfish, lobster and crab often lose a great claw in fighting, and sometimes the same thing happens when they cast their shells. It is very advantageous that they should be able to regenerate the lost part. In the higher animals the power of regeneration is much less developed, and whilst in the birds and mammals a broken bone may be repaired by new tissue or a cut may heal up, lost fingers or internal organs removed in an operation are not regenerated.

Sexual Reproduction is the typical mode of reproduction of all multicellular animals (and plants), and one may divide the body into a part—the body proper or soma—which functions for a time only and then suffers death, and another part—the germ cells—which are nourished by the soma and which under certain circumstances may develop into new individuals. Why the cells of the soma should live only for a time has not yet been satisfactorily explained. Possibly some cells which constitute certain Sexual reproduction

of the organs, or perhaps all the cells, slowly accumulate waste substances which cannot be got rid of, and which eventually bring about a slowing down, and ultimately a cessation, of the activities of the protoplasm. The germ cells which are aggregated together and produced in what we call the **Reproductive Organs** are free from these inhibiting factors.

The germ cells

The germ cells are of two kinds, the spermatozoa produced by the male and the eggs produced by the female. These cells are generally very unlike in appearance. Typical eggs resemble typical cells of rather large size, but the spermatozoa are exceedingly small, thread-like bodies, consisting of a so-called head and a long flagellum-like tail.

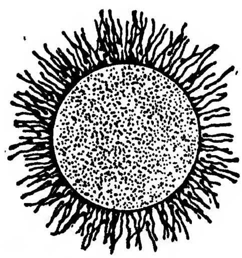


FIG. 182.—Egg of sea urchin surrounded by spermatozoa.

The illustrations (Figs. 182 and 183) show a typical egg and spermatozoa—the relative size of the spermatozoa is shown in Fig. 182. (It has been calculated that the sea-urchin spermatozoon contains only $\frac{1}{100000}$ the material of the egg.) Notwithstanding these great differences in shape and size, the spermatozoon is equivalent to the egg, and so far as we know both play an equal part in that handing on of characters from the parents which we speak of as heredity. As a matter of fact the spermatozoon develops from a typical cell (Fig. 185), the nucleus of which eventually forms the greater part of the head, whilst part of the protoplasm is present in the form of the tail.

The difference in shape and size of eggs and spermatozoa is explained by the fact that before these germ cells can develop into new individuals a spermatozoon must unite with an egg. (This union is termed **Fertilisation.**) To

facilitate both this and the development of the new individual the egg is non-motile, but carries a store of food material (the yolk), whilst the sperm is without a heavy store of this kind, but is capable of active movement, so that it may come into contact with the egg.

The size of the egg is not related to the size of the organism producing it, but to the amount of food stored within it. Thus the eggs of mammals are only a small fraction of an inch in diameter. The mouse egg is only 0·065 mm.

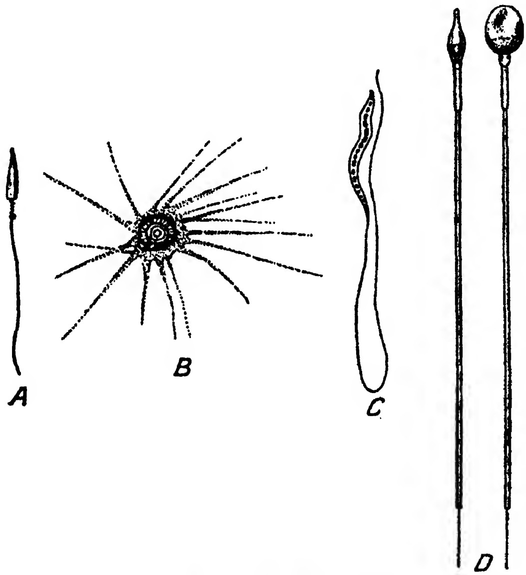


FIG. 183.—Some types of Spermatozoa.
B is an unusual type found in the Crustacea.

in diameter, the human egg $\frac{1}{120}$ inch. In the dogfish and its relatives, and the reptiles and birds, the store of yolk is so large that its volume is greatly in excess of the original cytoplasm, and the result is that the egg comes to be perhaps two or three inches in diameter. The most common egg, that of the domestic fowl, must not therefore be regarded as a type of all animal eggs.

The Production and Maturation of the Eggs and Spermatozoa.

Contrary to what might be expected, the germ cells are being produced in the reproductive organs long before the

Maturation of eggs and spermatozoa

animal is sexually mature. In fact, in many animals the commencement of germ cell formation may be recognised in the earliest stages of embryonic development. In most animals (practically all those higher than the Sponges) the germ cells are localised in the organs called **Ovaries** and **Testes**, according to the kind of germ cell which is being produced. In the early stages these organs are just groups of rapidly proliferating cells, generally to be found on the wall of the coelom. These little masses of cells include the primordial germ cells, the forerunners of all the germ cells. There

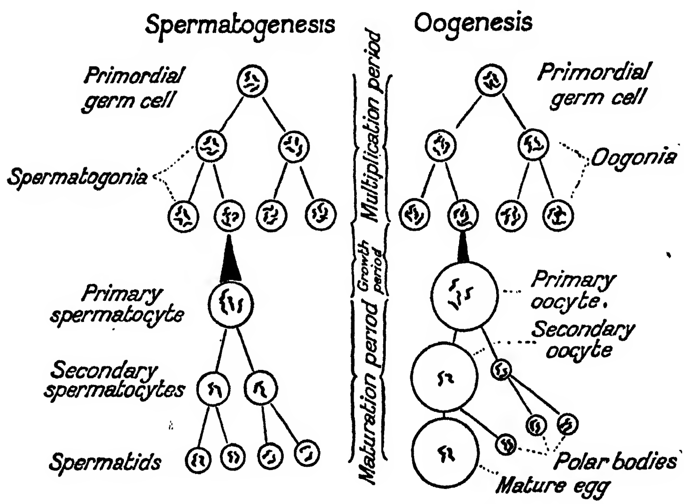


FIG. 184.—Diagram illustrating spermatogenesis and oogenesis (see text).

are often other cells among them, as for example cells which will build up the reproductive organ in all the complexity which ensues in some cases. We shall here confine our attention to the germ cells. A period of cell multiplication results in the primordial germ cells giving rise to a greater and greater number of cells as the animal and its reproductive organs increase in size. The cells which result from this multiplication are known as **Oogonia** in the female and **Spermatogonia** in the male. This period in the history of the germ cells terminates in a growth period, in which the cells which have been formed become more specialised, so at this point there is a more distinct difference than has up to now been the case in the development of the two sorts of

germ cells. The oogonia increase in size very considerably during the growth period and yolk is deposited in the cytoplasm. The spermatogonia do not change to anything like the same extent. The result is that we now have in the one case **Primary Oocytes** and in the other **Primary Spermatocytes.** Although differing in size they are equivalent, and in fact the rest of the history of development is essentially the same, although the two sorts of germ cells present apparently great differences.

The primary oocyte looks generally like a ripe egg. It is not, however, fertilisable until certain changes have taken

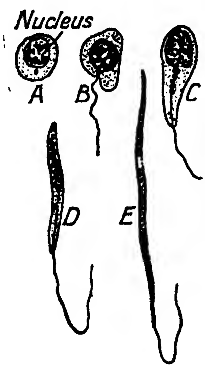


FIG. 185.—Development of a spermatozoon of the frog from a cell (the spermatid) having the more usual form. (After Broman.)

place. The primary spermatocyte has to produce four **Spermatozoa.**

Chromosomes and the maturation of eggs and spermatozoa

To appreciate these steps we must consider the *internal* structure of the germ cells and in particular the chromosomes within the nucleus. It was the discovery of the events now to be described which led to the most fascinating modern discoveries in connection with heredity. We have shown how during cell division a definite number of chromosomes appears in the nucleus and how these are split and distributed equally to the two resulting cells. This is true also for the multiplication of cells in the ovary and testis, and at all the divisions which result in the production of a large number of oogonia or spermatogonia the characteristic number of chromosomes is to be seen. Now if ordinary mitosis took place in all the *succeeding* divisions, we should have eggs and spermatozoa which likewise contained the characteristic number of

chromosomes. But at fertilisation two of these cells meet and fuse. This would result in the fertilised egg having double the proper number of chromosomes. It must be obvious, as it was to scientists before the explanation was discovered, that somewhere a reduction in chromosome number must take place or else every fertilisation would double the number of chromosomes. Each generation would thus possess twice the number of chromosomes in its cells that the preceding generation possessed.

The solution of the problem lies in the events which follow the production of primary oocytes and spermatocytes. Two divisions only take place, but these are very definite and very important. The first nuclear division is very different from a typical mitotic division, for the individual chromosomes following certain special phenomena are distributed equally between the two resultant cells. The result is that if the primary oocytes and spermatocytes had, say, four chromosomes (like all the other cells of our particular example) the secondary oocytes and spermatocytes would only have two each. The stages in this division, together with the following one, comprise the phenomena termed **Meiosis.**

But there is another feature which marks a difference between the development of the female and the male germ cells. The primary spermatocytes divide equally in all respects, and so the two secondary spermatocytes are equal in size. Whilst, however, the nucleus of the primary oocyte divides equally, the cytoplasm does not and so, instead of two secondary oocytes, we have only one and a little cell which is called the **Polar Body.** Both are really equivalent, but the secondary oocyte has kept all the yolk. Thus as a rule the polar body is incapable of becoming a ripe egg. We now come to the last stage. The secondary spermatocytes divide by mitosis giving two **Spermatids** from each, which rapidly develop into **Spermatozoa.** The secondary oocyte divides and so does the first polar body, but the division of the former is again unequal, so far as the cytoplasm and yolk is concerned, and consequently we have one ripe egg and three polar bodies resulting from the divisions of each primary oocyte. These stages of Meiosis which result in the ripe egg and the polar bodies, or on the other hand in the formation of four spermatozoa are collectively known as **Maturation Stages.**

This is the history of the development of ripe eggs and spermatozoa in the reproductive organs of the Metazoa. The last stages are important because we can see from them that if the chromosomes are responsible for carrying the factors which are inherited, the germ cells will not necessarily have all the characters of its parent (for it has only half the chromosomes). We also see that the new individual to be produced will receive half its chromosome complement from one parent (by way of the egg) and half from the other parent (by way of the spermatozoon), although the egg and the spermatozoon are so different in size. All this fits in with the results obtained in the crossing and breeding of both animals and plants, and it has resulted in the chromosomes being regarded as highly important if not all important in the mechanism of inheritance.

Germ cells of hydra

In *Hydra* eggs and spermatozoa are both produced by one individual (see Fig. 38). We cannot speak of it as male or female. It is termed **Hermaphrodite.** The male germ cells are produced from small non-specialised interstitial cells which lie between the large cells of the outer layer of the body wall. These **Interstitial Cells** multiply by fission and form a little swelling (sometimes several such are developed), situated close to the ring of tentacles. The cells contained in each swelling are known as **Spermatocytes,** and the swelling is a male reproductive organ—a **Testis.** Each spermatocyte by two divisions produces four **Spermatozoa,** which are set free into the surrounding water by the breaking of the wall of the testis. They swim about but do not live long. If one of these reaches a ripe egg, union may take place.

The early development of the ovary is similar to that of the testis except that its position is near the basal attachment disc. In this case, however, after the first multiplication of the interstitial cells, one of them devours the rest (like an Amoeba feeding by means of pseudopodia) and thus it greatly increases in size. The result is that the reproductive organ, known in this case as the **Ovary,** contains only one cell, an **Oocyte.** The result of the growth of the oocyte is that the cells of the outer wall of the ovary

are stretched and eventually they break and shrink back so that the oocyte protrudes. The nuclear divisions now take place which are part of the phenomenon known as Maturation (see previous pages), and the oocyte thus becomes an egg awaiting fertilisation by a spermatozoon. The result of a fertilisation union is that a single cell is produced called a **Zygote,** which generally commences to divide at once and gradually develops into a multicellular organism. In the case of *Hydra*, after the divisions have given rise to a little embryo consisting of an outer layer and an inner mass of cells, a horny covering is secreted by the outer cells and the embryo thus protected ceases to grow and falls to the bottom of the pond where it may remain dormant for several weeks or even through the winter months when the parents are killed off by frost. (See Practical Work, page 365).

In many aquatic animals the eggs and spermatozoa are shed into the water at the breeding season and the union of the two different kinds of cells, that is, fertilisation, is a matter of chance and the active motion of the spermatozoa. But the motility does not generally amount to much, and in order that there should be some chance that a reasonable number of eggs are fertilised, huge numbers of eggs and especially of spermatozoa are developed and set free. It has been calculated in numerous examples that there are millions of spermatozoa produced for every egg.

Fertilisation of eggs of sea urchin

For those who live at the seaside or who can obtain live sea urchins in the springtime, it is easy to demonstrate fertilisation and the resultant development. Male and female sea urchins are alike in appearance, and consequently one must break them open to determine the sex; even then it will be found necessary to examine a fragment of the reproductive organs under the low power of a microscope. If the reproductive organs are mature, the eggs will separate easily when a small piece of ovary is broken up in sea water. It is best to run this through a piece of muslin to remove the coarse fragments, but the mesh must allow the eggs to pass through readily. Now break up a little of the testis from a male into another glass of sea

water and add some of this fluid to the glass of sea water containing the eggs. After a few minutes examine some of the eggs under the microscope. Each one will be surrounded by a 'halo' of spermatozoa. It is not possible in such a preparation to see which spermatozoon enters the egg and fertilises it, but successful fertilisation is clearly indicated by the formation of a delicate transparent membrane round the egg. If the fertilised eggs are kept in small flat glass dishes, the results of fertilisation can be watched and the development traced until small larvae are formed.

Association of animals at breeding seasons

The simple type of sexual reproduction exhibited by Hydra and the sea urchin is not altogether confined to the lowest groups, but of course it is confined to aquatic animals. It would not only be impossible for the spermatozoa to move about on, say, dry earth, but unless the eggs and sperms were deposited under special conditions, they would soon dry up and death would take place. The highest group in which eggs and sperms are shed freely into water is that of the fishes. Of course, in these cases there would be little or no chance of fertilisation if eggs and spermatozoa were shed into the sea indiscriminately; the chances of an egg and a spermatozoon accidentally meeting would be very small. And so we find that at the reproductive season, individuals of both sexes tend to collect together and often they may migrate long distances to do so.

In some cases the two sexes enter into a little closer relationship than by the mere collection of large numbers on breeding grounds. In these circumstances the mating is more intimate. The salmon, for example, travel from the sea to the upper reaches of rivers where, they separate in pairs and prepare a place for spawning in about two feet of water. First a hollow is made in the gravel by lashing with the tail and then the female extrudes the eggs. The male fish, which is in attendance all the time, sheds the spermatozoa over them. The eggs are then covered with gravel and left. They hatch in about 5 to 21 weeks.

But even the association of aquatic animals like the above is not the most economic mode of reproduction, and still

less is this the case in the open sea where the fish are merely in shoals and the eggs and sperm are extruded. The result, as we have seen, is that enormous numbers of eggs have to be produced to balance the loss that occurs in the early stages. A female sea urchin is said to discharge as many as 20 million eggs in a season. The common codfish produces 4,520,000 eggs and the ling 18,000,000 each season.[1] The number of sperm cells is, of course, correspondingly enormous.

Thus to reduce this waste and make fertilisation more certain one finds in many groups of animals that the spermatozoa are introduced more directly into the body of the female so that they may reach the eggs. This, of course, is absolutely necessary if eggs are surrounded with a shell before extrusion, for a spermatozoon could not normally penetrate a hard shell. The egg must in such cases be fertilised internally before the egg shell is formed round it. A gradual series of stages leading to this certain method may be found. Thus, the plaice merely shed their reproductive cells into the water, and it is possible at the breeding season (and actually the method adopted in some fish hatcheries) to squeeze out eggs or spermatozoa according to the sex of the fish by gentle pressure of the hands ; the male and female salmon keep close in pairs and the male sheds the sperms over the eggs.

In the common newt of our ponds, the male emits the spermatozoa in little packets after quite an amorous display around the female. These packets, or spermatophores, are deposited in or on the sand and the female crawls over them and picks them up with the lips of the cloacal aperture. Within her body the spermatozoa are set free and after travelling up the oviduct reach the eggs.

The male crayfish deposits the spermatozoa, by means of the modified first abdominal appendages, actually on the surface of the body of the female near the openings of the oviducts. The male frog clasps the female frog and sheds the spermatozoa over the eggs as they leave her body.

[1] Compared with these the salmon producing 13,000 eggs and the herring 33,000 eggs, are not nearly so fecund.

It is only another stage beyond this to get actual insertion of the spermatozoa into the body of the female.

In the Honey Bee, as we have already seen, there are three types of individuals, the workers (undeveloped

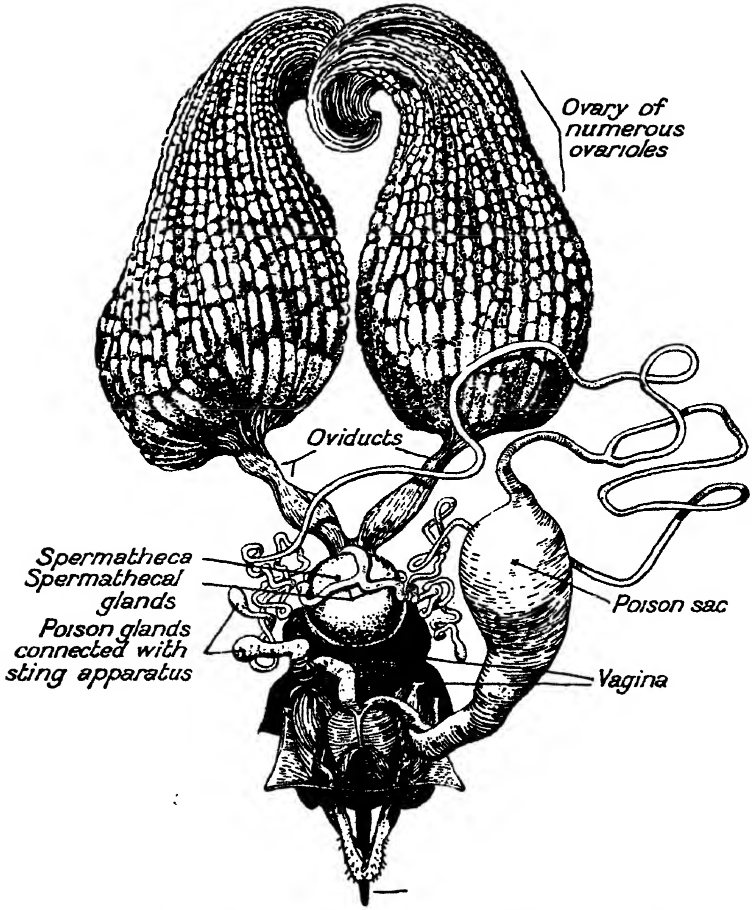


FIG. 186.—Reproductive organs, sting and poison glands of Queen Bee. (From Snodgrass.)

females), the males, and the Queens (the egg-laying females). The Queen Bee receives spermatozoa from a male only once in her life at the beginning of her egg laying period, which may last for several years. This insemination takes place high up in the air, and as the effort has been described

in wonderful language by Maeterlinck, we may well refer the reader to that author's *Life of the Bee.*

Reproduction of earthworms

In another of our types, the earthworm, reproduction is a little more complicated, because every earthworm is hermaphrodite (compare with *Hydra*). This condition, although not common in the animal kingdom (it is quite

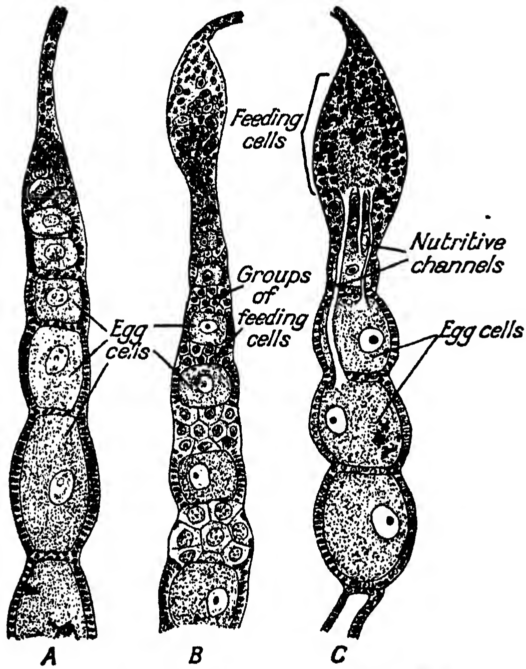


FIG. 187.—Diagrams of ovarian tubules of insects.

A. Cockroach type with no nutritive cells.
B. Beetle type with groups of feeding cells between eggs.
C. Hemiptera type with groups of feeding cells at end and nutritive channels to eggs. (After Korschelt and Heider.)

common amongst the flowering plants), is met with here and there and a few animal groups, like the tape-worms, are entirely hermaphrodite. When the reproductive organs of two neighbouring earthworms are mature, the worms apply themselves together and spermatozoa pass from each to the other. They are stored, however, in small bags, the **Spermathecae,** which do not open into the reproductive system, but have only their apertures to the exterior. At a later date when the worms have gone their own way,

each extrudes its eggs into a bandlike cocoon which has been secreted by the cells of a thickened part of the body (the **Clitellum,** see Fig. 189), and as this band is slipped off over the head, it passes the apertures of the spermathecae. Some of the spermatozoa are forced out, and thus eggs and sperm are enclosed in the cocoon where fertilisation takes place. It is outside the body, but it is nevertheless in a sheltered place. The spermatozoa have been passed over directly from one individual to the other.

The passage of sperm cells from the male into the body of the female takes place in the snail and many univalve

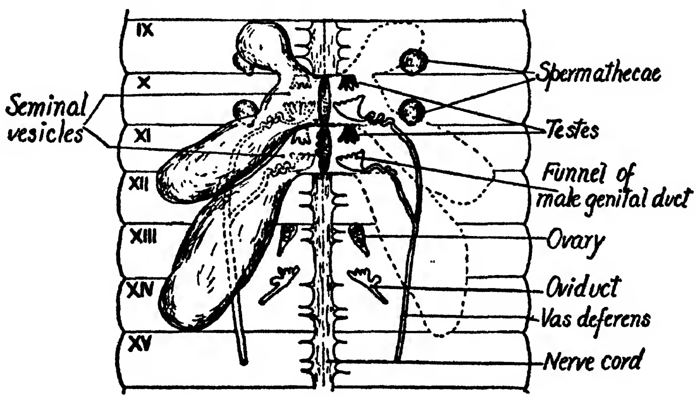


FIG. 188.—Reproductive organs of earthworm. (Roman numerals indicate the segments in which these organs lie.)

molluscs (but not in the bivalves like the mussel, cockle and oyster), in all insects, many crustacea and in most vertebrates (except the majority of the fishes and Amphibia).

After fertilisation, it is only a stage further to have the eggs retained on or within some brood cavity of the mother. This gives great protection during the precarious early stages. The crayfish, crab and lobster carry the developing eggs on the abdominal limbs until the young hatch out. The small Daphnia of fresh water ponds carry the developing eggs during the summer within a brood pouch on the dorsal surface of the body.

In the vertebrates, where the eggs are often retained until they have developed into young, this generally takes

Reproduction in vertebrates

place within some part of the tube leading from the body cavity to the exterior—the oviduct or its specialised region, the **Uterus**. This method is found in some of the fishes, especially in some species of sharks where the young are born alive as little sharks ; it is met with again in some of the reptiles, although many of these lay eggs as do the birds. It reaches its highest development in the Mammalia. The retention of eggs during development in this case has led to a direct organic relation between the developing embryos and the wall of the cavity in which they lie in the mother. In the sharks and reptiles there is little more than a retention of large yolked eggs, which use up the yolk just as if they had been laid enclosed in a shell.

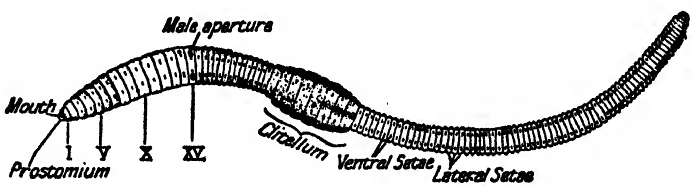


Fig. 189.—Earthworm.

In the mammals, the yolk is missing and, as stated above, the eggs are very small and the embryos receive both food and oxygen by way of the blood vessels of the wall of the uterus in which they are lying.

The birds and many of the reptiles lay eggs which develop inside a shell, but often amongst reptiles, the eggs are protected for a short period, whilst among the birds, it is usual for the two parents to remain in association during a season and to build a nest in which the eggs are guarded and kept at the necessary temperature for development. In this group and also amongst mammals, the young in many cases are at first rather helpless and need to be nursed by their parents.

Sexual reproduction leads in fact to an association between the sexes which may be of greater or less duration, and all grades are met with from the mere congregation in shoals at the breeding season (fishes), to the courtship and pairing so characteristic of birds and mammals.

But we must retrace our steps a little. The very interesting development of reproductive processes, so that fertilisation is ensured with economy and certainty by the insertion of the spermatozoa in the neighbourhood of, on, or actually inside the female, results in the development of a host of structures and of remarkable habits which may assist or be necessary to these types of reproduction. The males will require organs for the insertion of spermatozoa into the female, whilst the reproductive ducts of the female may have to be specialised for the secretion of egg shells or

FIG. 190.—Recently hatched crayfish on swimmerets of mother. × 4. (After Huxley.)

the nutrition of living embryos. In addition to these modifications, there are others which are less essential and many which play no direct part and scarcely an indirect part in reproduction, but are a consequence of the presence of certain reproductive organs. Examples of these are the mane of the lion, the comb of the cock and differences of the voice. And thus we find the males and females most often very unlike externally. Indeed although the essential difference between the sexes lies in the reproductive organs, we generally recognise the two sexes by their different external characters.

All these different characters which are linked up with

Secondary sexual characters

sex are often termed **Secondary Sexual Characters** in contrast to the reproductive organs themselves. In the crayfish they include the appendages of the abdomen (see Fig. 245), in the bee an elaborate apparatus in the male for the insertion of spermatozoa into the female and also other differences in the shape and size of the two sexes.

In the dogfish the so-called claspers on the pelvic fins of the male are secondary sexual characters, and the brilliant colours of the males of some bony fishes (especially at the breeding season), belong also to this category. The thumb pad of the male frog is another example. Amongst birds the secondary sexual characters are much more extensively

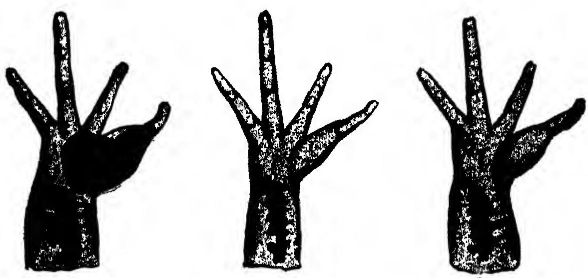


Fig. 191.
A. Right hand of male frog in breeding season.
B. Right hand of female frog in breeding season.
C. Hand of male frog out of breeding season. (From Borradaile.)

developed and often there is a great difference in the plumage of the two sexes, as, for example, in the peacock and peahen. The domestic fowl is just as good an example, the ornamental plumage of the cock and the spurs are all secondary sexual characters ; so is the behaviour, which is often very remarkable. Display in the case of the peacock and the courtship movements in many other examples of birds may be cited.

Frequently amongst vertebrates, the secondary sexual characters do not develop completely until after the reproductive organs are well established and in some instances not until they are mature. Again in a few cases, like the male Warty Newt (*Molge cristata*), there are conspicuous secondary sexual characters which develop each breeding

season when the testis is in full activity. There would seem therefore to be some intimate relationship between the reproductive organs and the secondary sexual characters in vertebrates; this is apparently not usual in invertebrates. Such a relationship is proved by the fact that the removal of the ovaries from a female Rouen duck results in the development of the plumage of the male sex, and recently the general public have been interested in hens that gave up laying and developed the plumage and habits of the cock. Internal examination of these birds has shown in many cases that the ovary was diseased.[1]

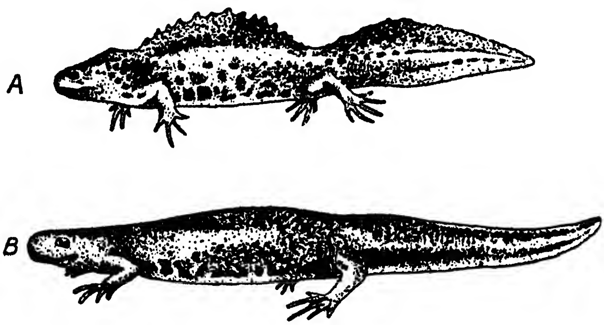


FIG. 192.—Newt (*Molge cristata*).
A. Male. *B*. Female. (After Cunningham.)

Determination of sex

We shall refer to this matter again in another chapter. At this point it is only necessary to remember that *in the invertebrates the fertilised egg has an initial bias in favour of male or female development and this applies to every cell in the body that results from the segmentation of that egg.* The secondary sexual characters are independent of the reproductive organs and the nature of both is determined by the original bias in the fertilised egg. In the vertebrates this is not exactly the case. The fertilised egg has a bias in favour of male or female development and so have all the cells which result from it, but when the reproductive organs develop they evidently produce substances which accentuate

[1] At least one case is known of a complete change from hen to cock, but this does not concern us here where we are dealing only with secondary sexual characters.

the bias already present, or reinforce it, and so exert an influence on the development of the secondary sexual characters. This action is so powerful that removal of the reproductive organs (as in the case referred to above) may permit the secondary characters of the opposite sex to develop.

Breeding seasons

As a rule, sexual reproduction amongst multicellular animals takes place at certain regular intervals or breeding seasons and very often these are correlated with the climate at different seasons of the year. Usually the breeding season is at a time when conditions are most favourable for the young and sometimes (as in the case of the migratory birds) the animals may migrate to a place which is particularly suitable. In England the frogs and toads breed during the early months of spring and the young stages are found in ponds during the summer. In many parts of Australia, however, where during the prolonged dry and hot summer the ponds evaporate, but where the winters are not generally colder than English spring, the breeding season occurs during the autumn or rather the beginning of the winter.

Marine animals are not so rigidly dependent on the climatic changes of the seasons, but quite a number of the common animals of our coasts--sea urchins, starfish, barnacles, plaice, etc., breed in the spring and early summer. In the tropics, on the other hand, where there is little change all through the year, there are cases where reproduction may go on at intervals throughout the whole year. In other and more peculiar cases the temperature is not the controlling factor. The Atlantic and South Pacific Palolo worms breed twice in the year near or upon the day of the last quarter of the moon, but in the case of the first named, it is in June and July, whilst with the second it is October and November.

It is on the whole rare for breeding to take place continually or even for there to be a succession of breeding periods during the whole year. The domestic fowl has a resting season during which the oviduct is reduced in size. The wild rabbit breeds during February to May (or later)

in England, although domesticated rabbits may breed almost the whole year if conditions are favourable. In fact, domestication usually tends to lengthen the breeding season. The breeding season for some of our sheep (that is, highland sheep) is before winter, namely from the middle of November until the end of the year. Lowland sheep breed earlier and lambs may be dropped by Christmas (the period of gestation is about 21 weeks). But some varieties of sheep in England may have two breeding seasons in the year. This again is more common in Australia where lambs may be obtained over a great part of the year. There is great variability in the sexual activity of the sheep and it is affected markedly by food and climate.

The crayfish associate during the last quarter of the year.

Parthenogenesis

In some cases peculiar cycles of reproduction are found, as in the familiar pond crustacean, *Daphnia*, and also in certain insects (the Aphids are common examples). In *Daphnia* a period of sexual reproduction in which two sexes are concerned alternates with a period of sexual reproduction in which the eggs develop without fertilisation (we have already mentioned this possibility in reference to the honey bee); this is known as parthenogenetic development or **Parthenogenesis**. The non-parthenogenetic eggs (often called winter eggs), which require fertilisation, are different from those which will develop without it, and the eventual history is different. The parthenogenetic eggs may be produced in large numbers; they are thin-shelled and contain little yolk. They are carried in a brood space between the dorsal wall of the thorax and the carapace (see Fig. 28), until they hatch and leave the brood pouch, a matter of a few days. The **winter eggs** which must be fertilised have hard shells and more yolk and they are deposited (one or two only) in a little case or **Ephippium.** They develop after a long resting period, which in this country endures through the winter. It is for this reason that these eggs are often called winter eggs. In our ponds the cycle runs as follows. In the springtime young female Daphnias hatch out of the fertilised eggs which have rested

through the winter. These females lay eggs which without any fertilisation produce another race of females and thus initiate another parthenogenetic cycle and this is repeated so that a rapid production of Daphnia takes place. Every individual is an egg layer and there are none of the risks which are involved in fertilisation.[1] In a few weeks there may be thousands of Daphnias (for on the average, these individuals are mature in 10 to 12 days), where previously none could be seen. It is generally only towards the autumn that males as well as females are produced from parthenogenetic eggs, but in some cases they may be found in summer and even earlier. These females produce the winter eggs which are fertilised by spermatozoa from the males, and they are thrown off from the body of the mother enclosed in the Ephippium. There are many minor variations of this life history in related genera and in some cases there is more than one sexual cycle in a year.

Reproduction in domestic fowl

To complete our account of sexual reproduction we may take a bird and a mammal such as the rabbit, as examples. Since, however, very complete descriptions are given in many text books of the actual development of the young in both these cases (embryology), we shall confine ourselves to a general description of the phenomena involved.

There is only one ovary and one oviduct in the fowl and these structures belong to the left side. When the female bird has attained maturity and the breeding season is reached, the ovary is a large organ consisting of a mass of smallish pellets of varying size (immature eggs undergoing development) and larger yellow balls varying in size up to about one inch in diameter. Reproduction, as we have already stated, is rhythmical and a long period of regular egg formation alternates with a short period of rest, which in England generally occurs in the winter months. But the origin of the eggs may be traced to a very early stage, in fact, it commences before the hatching of the chick, and

[1] It is in a similar manner by the production of a series of generations of parthenogenetic females that the Aphis (or green fly) so rapidly increase on our rose bushes in summer.

it is said that all the eggs which will be laid in the adult life are already present in the ovary at the period of hatching of the chick. They are of course very minute cells and it is only later that they commence to enlarge in turn and to store up yolk. This is gradually deposited throughout the cytoplasm of the egg cell except at one point near the surface where the nucleus lies. Eventually the egg cells become very large and bulge out from the wall of the ovary. The oviduct is now a large convoluted tube with thick muscular walls and with the upper end opening into the body cavity by a funnel-shaped mouth. The lower end opens with the alimentary canal into a cloaca which opens to the exterior.

A mature egg enters the oviduct either by the mouth of the oviduct actually grasping it as it bulges from the ovary or by the egg breaking away from the ovary and being picked up by the mouth of the oviduct. In the meantime, however, the female bird has received a supply of spermatozoa from the male and these have travelled up the oviduct until they actually reach the upper end where they may remain alive for some weeks. The result is that the egg (which at this stage is almost exactly like the yolk of a hen's egg as commonly understood) is surrounded by spermatozoa and fertilisation takes place. If the female has not received the spermatozoa, this does not affect the passage of the egg to the exterior in the way we are about to explain ; it simply means that the egg when laid has not been fertilised and will not develop. The egg is now conducted down the oviduct by muscular contractions (peristalsis) and as it passes down the upper part, the glandular walls of the oviduct secrete the **Albumen** (or white of egg). The egg rotates as it passes down and so the albumen is arranged spirally round the yolk and the thicker part forms two twisted strands (the **chalazae**). The next part of the oviduct secretes a thin but tough membrane, the **Shell Membrane**, round the albumen, and last of all a shell is secreted on the shell membrane and the egg is laid. The total period from the time the egg leaves the ovary to its being laid is somewhere between 21 and 26 hours.

Under abnormal circumstances antiperistaltic movements of the oviduct walls may cause an egg, already some distance down the oviduct, to go back again to the summit, where it may meet another egg coming in. As a result the two eggs may then pass down together and the egg membranes and shell will be secreted so as to enclose both.

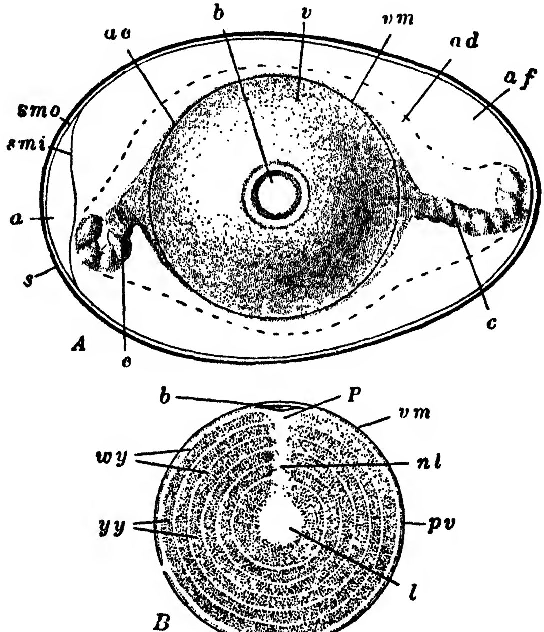


FIG. 193.—Egg of domestic fowl. (From O'Donoghue.)

A. Entire "Egg." *B*. Vertical section through ovum proper showing concentric layers of yolk.

a. Air chamber; *ac*., *ad*., dense albumen; *a.f*., fluid albumen; *b*. blastoderm; *c*., chalaza; *pv*., perivitelline space; *smi*., inner layer of shell membrane; *smo*., outer layer of shell membrane; *v*., yolk; *v.m*., vitelline membrane; *wy*., layers of white yolk; *yy*., yellow yolk.

The result is commonly known as a double yolked egg—in reality it is two eggs within one shell.

Of course, since fertilisation takes place (if it take place at all) near the summit of the bird's oviduct, development will commence and continue as the "egg" passes down the oviduct. When laid, therefore, it is in reality an egg no longer, but an embryo at a very early stage of development.

On coming in to the cold air, this development is stopped. It is an interesting fact that this cessation of development may continue for a little time without the possibility of further development being lost when the egg is put under a sitting hen or placed in an incubator.

Reproduction in rabbit

In the female rabbit, as in all other mammals, there are two ovaries, quite small organs (about $\frac{3}{8}$ in. × $\frac{1}{8}$ in.) situated in the body cavity and unconnected with the oviducts.

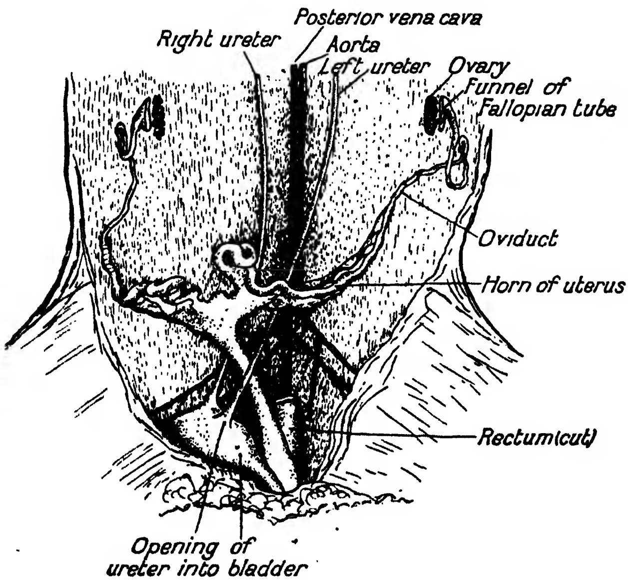


FIG. 194.—Reproductive organs of female rabbit.

The oviducts have little funnel-shaped mouths situated near the ovaries. Each oviduct runs backwards and enlarges to form a special section known as the **Uterus** and the two uteri join to form the **Vagina**, which opens to the exterior. The uterus is a very important cavity in the mammal, for it is here that the young develop.

In the male there are two testes, which are ovoid bodies developed in the body cavity like the ovaries, but passing backwards during growth until they come to lie in two pouches of the body wall known as the **Scrotal Sacs**. From

each testis a little tube, the **Vas deferens** (see Fig. 195), passes forwards. The two meet in a little sac, the uterus masculinus, and this opens into the canal leading from the bladder to the exterior. This canal, the **Urethra,** has therefore to serve for the passage of both excretory matter and spermatozoa. It runs through the organ known as the Penis.

As in the domestic fowl, the undeveloped eggs are probably all present in the ovary at a very early stage. They do not develop fully until the rabbit is sexually mature. Then, during the spring and summer (in England) eggs are discharged from the ovary at intervals of roughly a month. This is termed **Ovulation.** The mature eggs contain very little yolk and are therefore (like those of other mammals except the very lowest groups) exceedingly small. Those of the rabbit are only 0·12 mm. in diameter.

During the intervals when the eggs are ready to be set free, the female rabbit receives spermatozoa from the male and ovulation follows about nine hours or so after this act. The eggs are conducted into the oviduct and fertilisation takes place almost immediately, for the spermatozoa have made their way to the upper open ends of the oviducts.

Life history of mammals

We now come to an essential difference between the mammals and other groups of animals. The life history of the higher mammals may be divided into four periods. In the first place, the eggs are not extruded from the body after fertilisation, but are kept within the uterus of the mother where development takes place until the time comes for birth. This period is known as **Gestation,** and it may vary from days to months according to the species. In the rabbit, it is 30 to 32 days. (In the elephant it is as long as 20 months.) During this period the young develop from the egg, receiving nourishment from the uterus walls.

At the end of gestation there comes an abrupt physiological change, birth takes place and the young mammal is passed out to the exterior. It may be almost able to take care of itself at once (as, for example, the calf and others), but, in perhaps most cases, the newly born mammal is

very helpless and it is cared for by the mother. In any case, however, the young are dependent to some extent on the mother and a period follows when the young are nourished more or less upon *milk* produced by the mother

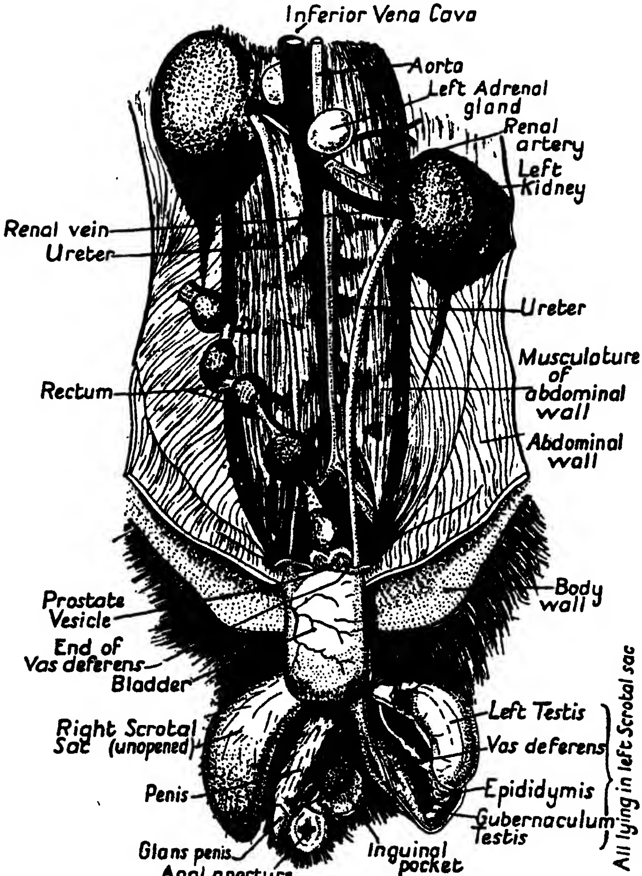


Fig. 195.—Urinogenital organs of male rabbit. (After Röseler and Lamprecht.)

in mammary glands. There are usually several pairs of these and the number bears some relation to the number of young which may be produced at a birth. This second stage in the life of a mammal is known as the period of **Lactation.** Following this there is a period of further

growth, **Adolescence,** which leads to sexual maturity and the adult stage.

Let us now go back to the point where we left the fertilised eggs—in the oviduct. They commence to develop and pass after three days into the uterus. At the same time as the ovary is passing through one of its periods associated with the setting free of eggs, the lining membrane (mucous membrane) of the uterus undergoes certain changes, becomes highly vascularised and modified for the reception of an embryo. If an embryo *is* formed, the whole uterus gradually undergoes modification. At the end of a few days each little embryo begins to attach itself to the uterus wall and very soon a close union is set up by a structure known as a **Placenta.**

The placenta in the rabbit has the shape of a thickened disc or cushion and is almost entirely developed from the embryo. Where the embryonic tissues lie in contact with the uterus wall, the epithelium of the latter disappears and consequently a special region of the embryo—the **Trophoblast**—is brought into immediate contact with the subepithelial tissue of the uterus. The uterine capillary blood vessels in this region burst and thus the blood oozes into spaces of this button-like area where the capillaries from the embryo are branching. The result is that the blood in the embryonic blood vessels of the placenta is only separated from the blood circulating in the uterus wall by the most delicate bounding walls, and with this the placental circulation is established. It must be noted that there is no direct circulation of blood from the mother into the developing embryo, but in the placenta the two circulations are brought very close together. They may be compared to two railways running to very different parts of an extensive country, but having a station in common where trains draw up on opposite sides of the same platform. Parcels and passengers may leave one train here and pass into the other.

In the placenta there is an interchange between the blood of the mother and the young somewhat similar to that which takes place in the various organs of the body;

oxygen and food supplies are handed over and carbon dioxide is taken away. Thus the placenta is the organ for nourishment and respiration during the period of gestation. It is important to remember, however, that even the smallest particles—like bacteria—seem unable to traverse the delicate membrane separating the maternal and embryonic blood and thus, although oxygen and food matters in solution may pass through, the embryo is protected from bacterial diseases which may be affecting the mother so long as the *placental structures remain unbroken.*

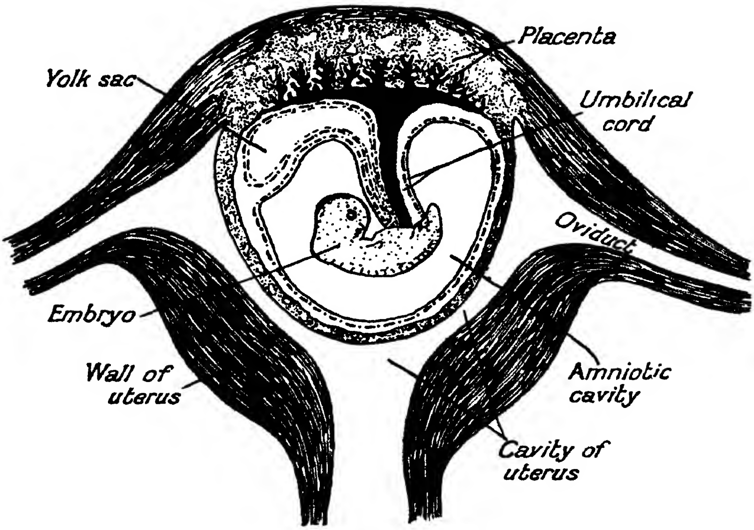


FIG. 196.—Diagram of embryo of mammal in uterus.

One or two more words may be added in regard to the uterus. Naturally, as the embryo or embryos develop and become larger, the uterus becomes distended. In the human uterus, the walls become thicker and altogether the cavity increases in size from a few c.c. to about 6,000 c.c. Curiously enough this extraordinary growth is not due to an increase in the number of cells, but to an increase in their size. In particular the muscle cells grow. The whole change is temporary, and after the birth of the embryo a remarkable shrinkage takes place until the uterus is once again reduced in size.

Importance of reproduction in nature

In concluding this section we may stress the fact that the study of the phenomena of sexual reproduction is one of the most fascinating of all branches of biological study. In the plant world in the flowering plants we are presented with most interesting and beautiful devices whose purpose is to ensure cross-fertilisation, to facilitate the conveyance of pollen from the male parts of one flower to the ovules of another. In the animal world we can trace the evolution of more and more complicated structures and habits which result in making fertilisation more certain and the early delicate stages of the developing young safer. They culminate in the remarkable habits connected with the care and nurture of the young, with courtship and nesting, and with the wonderful internal development of the embryo in mammals. In fact, nature often sacrifices all to ensure the production of a new generation. The Mayfly lives for two years as an aquatic larva in the mud at the bottom of a stream preparing for the brief winged existence of a few hours which is the time of mating and egg laying. It may endure through an evening, but morning finds the insect dead, the egg-laying completed and a new generation provided for. The male bee dies in the act of fertilising the queen.

Having regard then to the prime importance of reproduction as one of the outstanding characters of living organisms, it is not in the least surprising that the instincts which dominate and lead to reproduction are amongst the most powerful with which we are acquainted. This instinct control tends in the lower animals for safety; any abnormality, if it does occur, generally means death. Man, however, has the sublime power of choice, of exercising his will, and with this has a far greater chance of going wrong. Indeed he has to be taught to walk, to speak, to eat and drink wisely and so on. It is imperative, therefore, for a healthy life that we are normal in all things and that means that we understand the functions of the body and exercise them in a correct manner, not only for our welfare but for that of the society in which we live.

I. Spermatozoa can be easily obtained from the seminal

vesicle of the male frog in spring. They should be examined living and also stained. (A slide can be prepared in a similar manner to a blood smear, see page 463.) Spermatozoa may also be obtained from the sperm reservoirs of the earthworm. **Practical work on reproduction**

Sections of frog and rabbit ovary should be examined and a simple study of the hen's egg should be carried out.

II. With a little practice *Hydra* can be kept and bred in the laboratory. Specimens should be brought back from the ponds with sufficient pond water to set up a number of small aquaria (half pint glass tumblers). Fresh supplies of water will be necessary once a week in summer, and less often in winter. (Tap water may be tried, but in many places it kills the animals after a short time.) Success of the culture depends on the food. Either a culture of *Daphnia* must be set going (see below), or else visits to a pond with a plankton net must be made at frequent intervals. Quite a large number of small Crustacea must be given about twice a week—that is, sufficient for easy capture by the *Hydra*. The *Hydra* should form ovaries and testes and, of course, budding will also take place. Spermatozoa can be seen in active motion in ripe testes if a *Hydra* under a cover glass is examined with a compound microscope. A little pressure may set the sperms free. Fertilisation should take place in the aquaria.

The fertilisation and early development of sea urchins is a classic method of study and is very easily carried out at a seaside place where sea urchins are obtainable. Spring and early summer months. Other details are given in the text, page 344.

To set up a culture of *Daphnia*, make first a solution in the proportion of 25 grammes of Canary guano to 2½ gallons of rain water or pond water. Use heat. Cool, allow to settle and filter. Inoculate the filtrate with *Euglena* and some green algae common in ponds and allow to stand until a thick growth of alga has formed. Fifty drops of this thick culture should be added to 500 c.c. of water and the mixture inoculated with Daphnia. These cultures may

be used for studying reproduction in Daphnia as well as for feeding the Hydra.[1]

A study will naturally be made of the actual structures involved in reproduction in the usual types. Illustrations of the reproductive organs in the earthworm, queen bee, dogfish, frog and rabbit are given and should serve as guides to the dissections.

[1] Another simple method for Daphnia is the following. Have an aquarium jar, holding about 5 litres, well stocked with Daphnia. Mix a gram of Horlick's malted milk to a paste with boiling water, dilute to 50 ccs. and add to aquarium. Add this amount every week. Keep culture warm (60° F.).

XVII

ANIMAL DEVELOPMENT AND LIFE HISTORIES

It has been shown that in typical sexual reproduction the multicellular animal begins its existence as a single cell—the fertilised egg. The processes by which a single cell becomes converted into a multicellular animal will only be briefly treated in this chapter. There is a remarkable similarity in the early development of the different animal types, in fact, it is this evidence of a fundamental plan which forms one of the strongest evidences of evolution and the relationship of different animal groups. Notwithstanding this similarity, however, variations due to the presence or absence of yolk in the eggs and to special adaptations would necessitate a very large text-book to treat adequately even a few types.

Embryology of a hypothetical vertebrate

In all cases the fertilised egg commences its development by a series of cell divisions, which results in a little group of cells. Up to a point the segmentation is regular and it is always under control. Let us take a hypothetical type to illustrate the kind of thing that may take place (Figs. 197 and 198). (It is of interest to note that there is an animal in which the development from the egg is very like our generalised example. This is *Amphioxus*, a very lowly vertebrate. Unfortunately its early stages are not readily obtainable in the living state.)

Simplicity is the keynote of our example, and this is largely due to the fact that we will take an egg with little or no yolk. The unsegmented egg is so constituted that it possesses two opposite poles (like the North and South poles of the earth). The first division cuts the egg into two halves and it is a vertical or meridional division passing through the two poles. This is followed by another

meridional cut which divides both cells into two, making four. The third cleavage is equatorial or near it, cutting all four cells and thus making eight cells, and so cell division

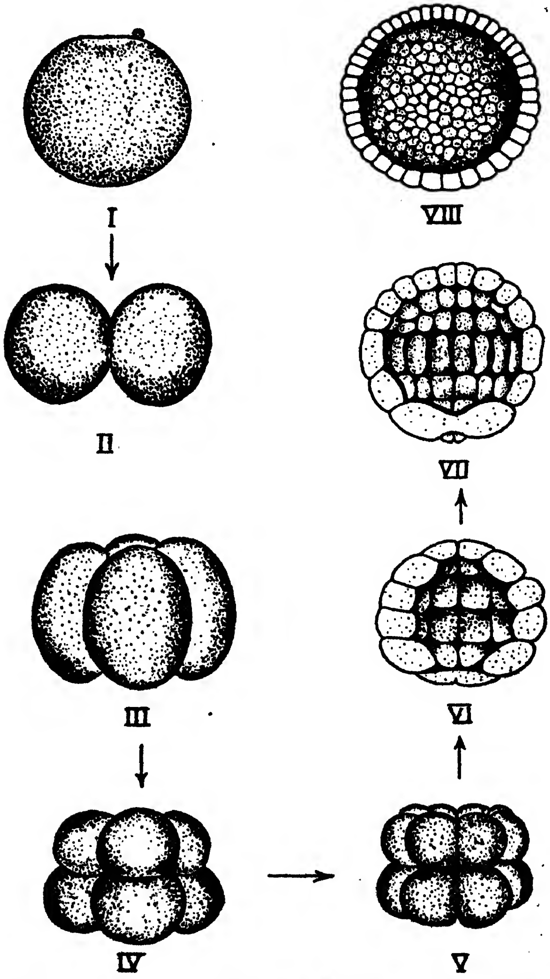


FIG. 197.—Diagram of development of the egg of a hypothetical vertebrate.

goes on giving 16 and 32 cells and then division becomes more irregular. It results in a little heap of cells like a minute blackberry (Fig. 197 V). By secretion of fluid within this mass, the cells push away leaving a central space and so eventually a hollow sphere is formed. This

is called a **Blastula** (diminutive of the Greek word Blastos = a bud). The blastula has a wall one cell thick. By this time there may be about 250 cells in the little

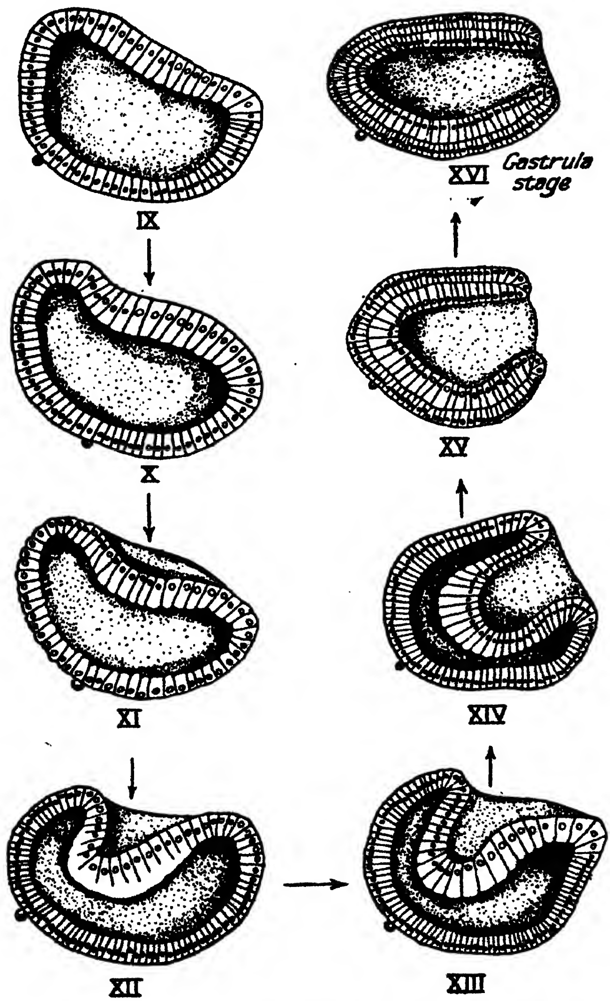


FIG. 198.—Further stages in development of hypothetical vertebrate.

embryo and this stage may be reached within four hours after fertilisation (Fig. 197 VIII).

The single layered embryo now becomes converted into one with a wall of two layers. In the type we are following

this is achieved by the wall first becoming flattened at one region (like a rubber ball pressed against a table) and this region then proceeds to bulge inwards. The 'bulging' is accomplished by further cell division and becomes more and more pronounced and encroaches on the original blastula cavity until the latter is practically obliterated, and we now have a two layered embryo (called a **Gastrula**), with a cavity open to the outside at one point (see Fig. 198). This ingrowth of a cell layer is known as **Invagination.** The outer layer of cells is called the **Ectoderm** and the inner layer the **Endoderm.** The new cavity is actually the earliest stage of the alimentary canal of the adult. All the stages so far described can be watched in the development of the sea urchin although this is an invertebrate, and we suggest that students who experiment with the fertilisation of sea urchin eggs should follow the embryology. It is not difficult to obtain embryos if the fertilised eggs are kept in little flat dishes of sea water, remembering that cleanliness is essential and that too many eggs should not be crowded together. However, our example represents a vertebrate type and we intend to show how those characteristic features, the brain and spinal cord and the backbone, originate.

From the gastrula stage onwards the development of vertebrates is quite different from that of invertebrates. In our hypothetical example, by continued cell division, the gastrula gradually becomes elongated until we can recognise the long axis of the adult. The development of the nervous system is then initiated by a strip of ectoderm lying along the mid-dorsal line becoming marked off from the rest. Two parallel folds appear in it and a channel or groove thus comes to lie between them along the mid-dorsal line (Fig. 199). The groove is the **Neural Groove** and marks the beginning of the nervous system. The neural folds gradually become more pronounced and inclined towards each other until they meet and fuse and a dorsal tube of ectoderm becomes cut off from the surface layer. This simple epithelial tube becomes the brain and spinal cord by expanding at the anterior end, by bending and more

especially by an enormous increase in the number of cells, causing great thickening of the wall in definite places. The cells which occasion these thickenings become specialised as nerve cells of different kinds and strands of nerve fibres grow out here and there and become the nerves, finding their way to all parts of the embryo, in which of course, other

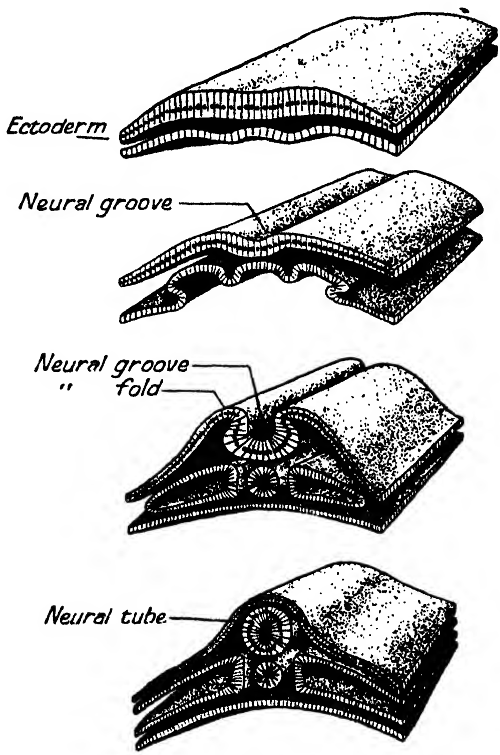


FIG. 199.—Development of nervous system in a vertebrate.

structures have been steadily developing whilst the events just described were taking place.

The development of the vertebral column always commences as a rod of cells called the **Notochord.** In our hypothetical example, this is formed from the strip of endoderm immediately below the neural groove. This strip of cells becomes folded off from the rest of the endoderm to form a solid rod (see Fig. 199).

The ectoderm and endoderm are known as germ layers. **The germ layers**

The ectoderm gives rise to the skin of the adult and to the nervous system and sense organs. There is a third germ layer called the **Mesoderm**, which gives rise to most of the tissues and organs between the skin and the alimentary canal, that is, to the muscles, much of the skeleton, to the blood and blood system, excretory and reproductive organs, etc. In our imaginary type, the mesoderm is derived from the endoderm by a succession of little outgrowths or pouches (as illustrated in Fig. 199). These become completely cut off from the endoderm, which now gives rise directly to the lining of the alimentary canal and by outgrowths to the lungs, the liver, the pancreas and other diverticula from the alimentary canal. The cavities in the mesoderm give rise to the body cavity.

Thus by continued cell division, accompanied by in-growths, outgrowths and foldings, and by specialisation of cells for one function or another, the embryo is gradually built up.

An account of the early development of the frog's egg is given in the Appendix. The simplicity of our example is missing because the frog's egg contains a considerable quantity of yolk which interferes with regular cell division. The volume of yolk in the bird's egg is so enormous that only one small area of the egg segments and consequently the embryo develops on top of this yolk mass.

Development of eye of chick

We have stated that all development is the result of cell division, foldings, outgrowths and specialisation; let us trace the development of a vertebrate eye as an example of this. We may take the eye of the chick as a type and commence at that embryonic stage where the neural tube has been formed in the way described for our imaginary animal. It lies dorsally just below the ectoderm. Anteriorly it is rather wide, for this is the brain region, and at the extreme anterior end it expands still further transversely, producing two lateral pouches. These outgrowths are the beginnings of the **Optic Vesicles.** As they gradually grow out towards the ectoderm, their connection with the brain becomes more stalk-like. (It should be noted that the development of the eye is initiated from within, actually

from the embryonic brain in these vertebrate types.) A thickening of the ectoderm now appears opposite the optic vesicle and this is the rudiment of the lens. Both the outer surface of the optic vesicle and the ectoderm now commence to infold (invaginate) as shown in the illustration (Fig. 200), and so the outgrowth from the brain becomes a two-layered optic cup, whilst the invaginated part of the ectoderm is cut off altogether and, by alteration in the cells, it gradually becomes a solid transparent lens.

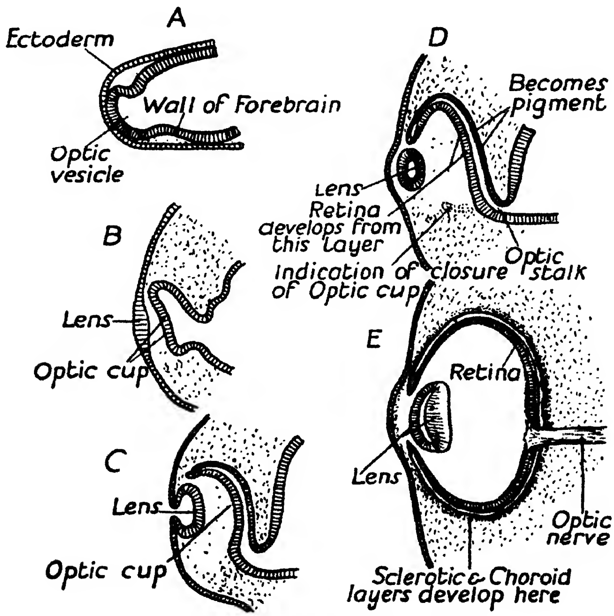


FIG. 200.—Development of eye of chick.

The optic cup is at first widely open, and, in fact, there is a depression in one side of it. Gradually it closes in to leave the small circular opening which will become the pupil. The inner layer of the optic cup becomes transformed into the retina by the increase of the cells and their modification to all the structures illustrated on page 307. From some of these cells long fibres grow out towards the optic stalk. They pass into its cavity and grow down it, gradually making it a solid nerve—the optic nerve. The outer layer of the optic cup degenerates, pigment is

deposited in its cells and it becomes the pigment-layer of the retina (see Fig. 200). Such is the formation of the essential parts of the eye. The outer layers, the choroid and the sclerotic are formed from mesoderm cells which gradually come to surround the optic cup and lens.

The development of such a wonderful mechanism as the vertebrate eye may appear rather simple. Its simplicity makes it none the less, but rather more, wonderful. Lest, however, the reader be left under a misapprehension, we may remind him that we have taken no account in this description of the extraordinary specialisation that goes on in the retina, of the remarkable harmony between the development of the different parts and of the invisible control which orders the infolding here, the cell division there and the specialisation everywhere. It is not altogether difficult to watch the development of an embryo, but very little is understood of the controlling mechanism which regulates the process.

Development with metamorphosis

In some cases the course of development of an animal from the egg to the adult exhibits a gradual approach to the adult form and structure, from which the early stages may not differ very greatly. In other animals the early stages may be quite unlike the adult and they may extend over a long period of time after which the adult form is developed by sudden changes of form. This sort of development is characteristic of the animal life histories with metamorphosis, familiar examples of which are the butterfly and other insects. When the young are very unlike the parent they are termed **Larvae** (Fig. 201). The tadpole is the larva of the frog. The caterpillar is the larva of the butterfly. In this case, however, the larva has become so unlike the adult that an intermediate resting stage represented by the pupa is interposed, during which reconstruction takes place. As examples of life histories we shall take the frog and two insects.

The eggs of the common English frog are fertilised (see Chapter on Reproduction), as they leave the body of the female. They are deposited in water and left to take care of themselves. As we have seen, the outer layer of albumen

Life history of frog

swells up as the result of absorbing water, and consequently the essential part of the egg is surrounded by a thick wall of jelly which separates it from its neighbours and protects it. Segmentation commences and a fairly typical blastula is formed, but then complications ensue. The egg remains spherical for about 36 hours or so and then one can gradually see, with the unaided eye, that the embryo is forming. This becomes more and more elongated and gradually a definite head region and a compressed body can be distinguished. With the low power of the

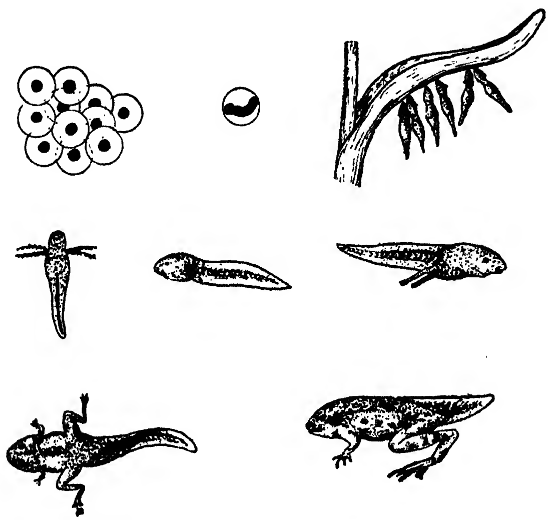


FIG. 201A.—Life History of frog.

microscope at this stage it may be possible to see a faint line indicating where the mouth will open and also the sucking disc below it. The rudiments of the gills are visible as two little projections on the sides of the head. At the end of a fortnight wriggling movements may be seen and the embryo gradually works its way out of the jelly sheath and becomes a tadpole. By this time rudiments of most of the organs are present, but the mouth depression does not open into the alimentary canal. The tadpoles hang on to floating weeds or other objects by means of the little adhesive discs and for a few days development continues, the remaining yolk serving as food.

With the breaking through of the mouth opening, the tadpoles become active and search for food, horny lips appear bounding the mouth, the alimentary canal begins to function and digestive glands develop. Rapid growth follows. Little feathered outgrowths, the external gills, are now quite distinct. Blood capillaries run into them and respiration takes place here for a time, but just when the mouth is opening, a series of little slits breaks through on each side into the alimentary canal and internal gills develop on the slit walls. The tadpole now resembles a little fish, in so far as its respiration and blood circulation is concerned.

The alimentary canal was first formed as a short tube, but owing to both ends remaining fixed whilst the length gradually increases, it becomes thrown into coils or more correctly that part of it which is the intestine. One can watch the development of this coiling through the body-wall of the tadpole.

Growth and organisation continue rapidly. The external gills disappear and projecting plates (the opercula) grow over and protect the gill slits. They eventually cover up the slits altogether and fuse with the body-wall, except at one little pore or *spiracle* on the left side. This single opening serves for the outward passage of the water, which, as in a fish, enters by the mouth and goes through the gill slits and over the gills to the exterior again. The tadpole gradually increases in size without much further external change until after several weeks (the time is entirely dependent upon the temperature and on good conditions of food, etc.) the rudiments of both pairs of legs appear. The rudiments of the fore limbs are, however, not visible externally, because they are covered by the operculum and so the hind limbs appear to develop first.

This is the external appearance of the tadpole towards the end of its period of existence as such, but lungs have developed internally and the creature may have been rising to the surface for air. Probably three months have elapsed since the egg was fertilised. Now with remarkable suddenness (a few days), this typically aquatic larva changes to a

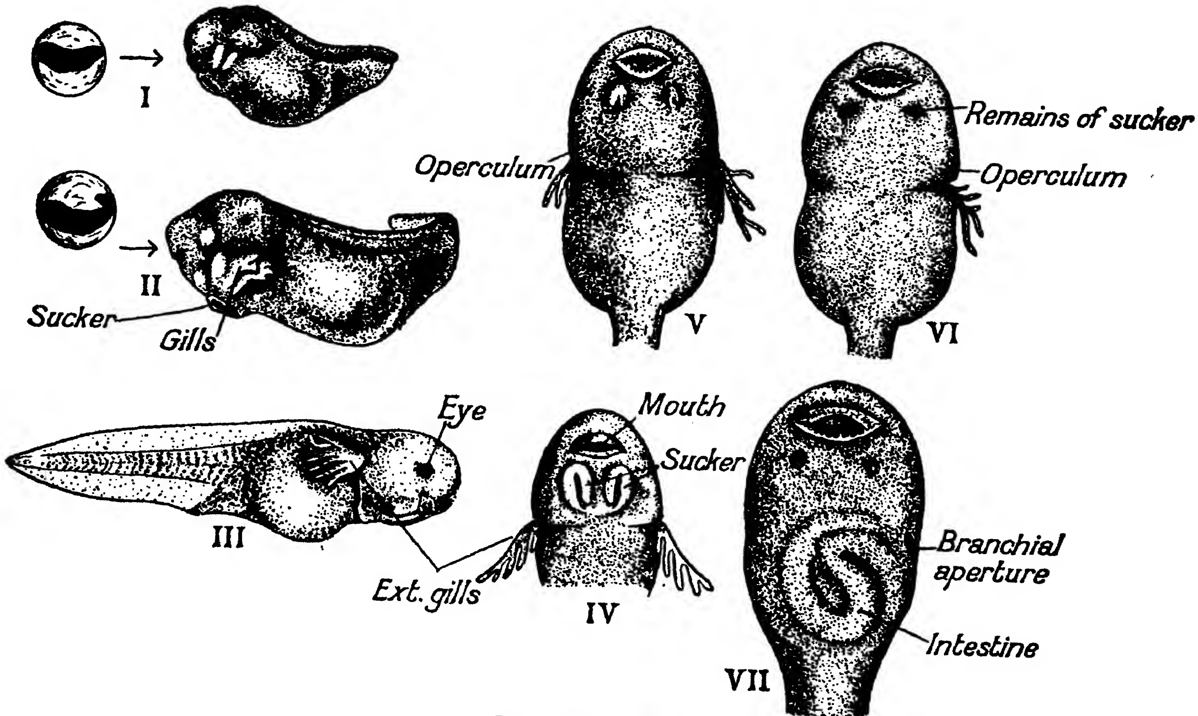


FIG. 201B.—Tadpoles.

I. Embryo before hatching. II. Embryo ready to hatch. III. Early tadpole with external gills. IV. Under surface of head of tadpole depicted in III. V. and VI. Under surface of tadpole showing disappearance of external gills and overgrowth of operculum. VII. Ext. gills disappeared.

small frog. The change is abrupt enough to be called a metamorphosis and it is a fascinating thing to study. The tadpole was largely a vegetarian with a long intestine, a gill-breather, and a fish-like swimmer dependent on a tail. It now ceases to feed for a time, casts off its outer skin, loses its horny jaws and extends the width of its mouth. It becomes adapted to a carnivorous life, its intestine shortens and the stomach enlarges. The small eyes become larger. The fore limbs, until now covered by the operculum, push their way out, the left one through the spiracle, the right one tearing the operculum. The gill slits close, gill breathing ceases and the lungs come fully into action. With this change, a characteristic alteration takes place in the blood system and the vessels passing to and from the lungs take up their full duty. At first a tail is still present, but this gradually is absorbed. The tadpole has become a frog.

Such is the life history of the frog. It calls for a little explanation. The interpretation usually put forward is that the sequence of events is something of a recapitulation of the ancestral history of the frogs, the tadpole representing a fish-like ancestral stage.

Life history of butterfly

Now let us contrast with this the life history of a butterfly and then the housefly. Both can be observed experimentally. The silkworm moth or the "cabbage white" may be encouraged to breed in captivity and every stage in development can be examined. The eggs are fertilised internally and laid by the female on the leaves of a suitable food plant (in the case of the silkworm moth, mulberry leaves are generally used). The cabbage white lays its eggs in May and again in late summer. From the egg, after the usual series of segmentation divisions and the organisation of the resultant cells (taking about a week), a small caterpillar hatches out. It has an elongated worm-like body, but the fact that it is not a worm is clearly indicated externally by the appendages on the first three segments after the head. They are typical five-jointed arthropod limbs ending in claws. These small caterpillars feed voraciously and, being bounded by an external cuticle

like all members of their class, they must throw it off before an increase in size may freely take place. At the commencement of development this moulting of the external

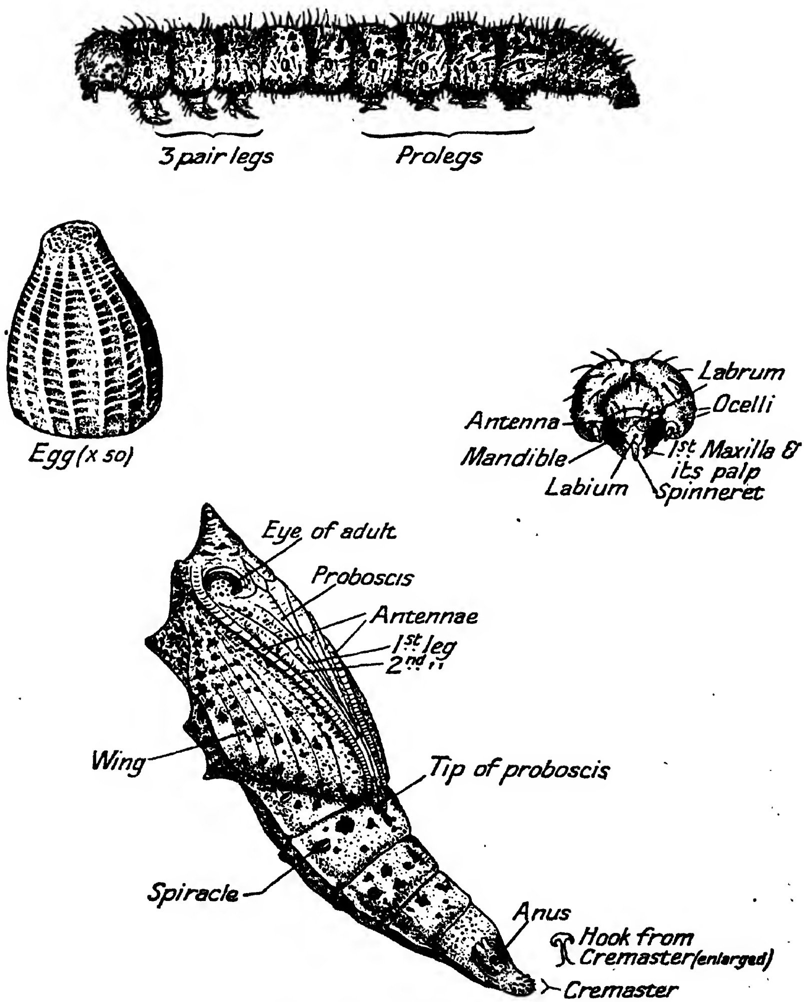


FIG. 202.—Stages in life history of cabbage white butterfly.

skeleton takes place very frequently—the first after a few days. Feeding stops at this time, then goes on again and a rapid increase in size is apparent. Moulting or **Ecdysis** may be followed by some slight external changes—the new

cuticle may vary in colour or in certain little projections, but there is no essential change in appearance or in the internal structure.

The larva consists of a head and thirteen segments. The first three segments, the thoracic, bear clawed legs, the remainder form the abdomen. Four of the abdominal segments bear each a pair of blunt processes, the **Prolegs.** Each one terminates in a cushion with a semicircular series of hooks. At the extreme end of the body another pair of pro-legs forms what are known as the **Claspers.** At a glance this larval stage is very unlike the winged butterfly. Closer examination indicates further differences. The head, which has a stout cuticle, has no large compound eyes,

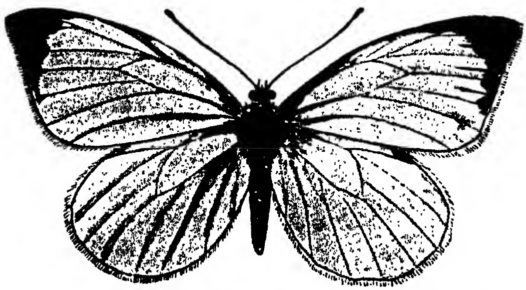


FIG. 203.—Adult cabbage white butterfly. (From Lulham.)

but only a group of ocelli. The **Antennae** are short, and there is a pair of strong biting **Mandibles** which serve the purpose of biting off the leaves. Behind the mandibles are other mouth appendages—**Maxillae** and the **Labium** or lower lip (see Fig. 202). In front of the latter is a small process bearing the aperture of the duct from the silk glands (remarkably large organs in the 'silkworm' caterpillar). The body is covered with little tubercles bearing short hairs. Internally an alimentary canal runs from mouth to anus and, compared with the butterfly stage, this presents an enormous stomach region. The silk glands are long tubes lying on each side of the stomach—the silk is a sticky fluid which hardens when it reaches the air. The breathing organs are, of course, tracheae (see page 113), opening at spiracles on the sides of the body.

When the caterpillar is fully grown, feeding stops, and the creature finds its way to a suitable spot for the next stage. In the case of the silkworm it now commences to spin a cocoon which completely encloses it. The cabbage white butterfly only spins a small quantity of silk, sufficient to suspend itself. The body then becomes much shortened and the cuticle splits along the back and is slowly worked off at the posterior end. The result, however, is a startling change in appearance and in structure. The caterpillar has become a **Pupa.** If its shape be examined carefully, one will recognise characteristic features of the winged

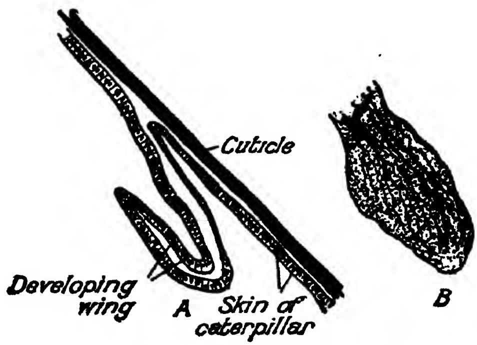


FIG. 204.—Development of wing of butterfly.
A. Developing wing under cuticle of caterpillar as seen in section.
B. The same rudimentary wing as it appears if dissected out. (After Carpenter.)

butterfly. The wings, legs and compound eyes can now be traced, but the mandibles have gone and there is an indication of the long sucking tube, the proboscis of the adult. The abdomen is short and there are no pro-legs. This ' sudden ' change is the first step in the metamorphosis. As a matter of fact, it is not so sudden as it looks, for rudiments of the wings had been developing earlier, but they were intucked below the thoracic body-wall (see Fig. 204). Rudiments of the other adult structures can be traced if we carefully dissect a caterpillar. Towards the end of the caterpillar's life these rudiments grow considerably and with the throwing off of the last caterpillar cuticle they are protruded and so the form of the pupa comes into being.

But the structure of the adult is not complete. In the

course of the resting pupal period, when life is only indicated by a little twitching of the abdominal segments if they are touched, a remarkable breaking down and reorganisation of structure takes place internally. This is one of the most curious features in the insect life history.

The pupal stage may be of very long duration. In summer it usually lasts only two or three weeks, but caterpillars which pupate in autumn rest as pupae throughout the winter. As is frequently the case in the animal kingdom, a resting period is used to tide over a difficult season. Eventually new organs are constructed, external conditions become suitable and the last change takes place. The pupal cuticle splits down the dorsal surface, the adult or **Imago** emerges and before the new cuticle hardens, the wings, which are still small and crumpled, expand and after reaching their full size stiffen up. No further growth can ever take place.

Life history of housefly

The life history of the housefly is very similar to that of the butterfly, but there is even a greater difference between the larva and imago. In this example we have a case of great importance from the point of view of public health, for the housefly has been shown to carry disease germs (typhoid fever, etc.) and to infect human food stuffs.

The female housefly deposits the eggs on decaying matter which is suitable as food for the larva. The most favoured substance has been found to be stable manure, but ashpit refuse, human excreta, decaying vegetables, milk and bad meat have all been registered as breeding places. The conditions required are a certain amount of moisture and a favourable temperature. The fly commences to breed in the summer months and a hundred or more eggs are laid at a time. (A single housefly may deposit five or six such batches of eggs in a life of three or four months.)

The eggs are whitish cigar-shaped structures about $\frac{1}{25}$ inch in length. They hatch within twelve hours if the temperature be moderately high, but may take longer. The larva which emerges is a limbless segmented creature which possesses only a small head and, since this is withdrawn into the anterior end, it appears headless. The

pointed end of the larva is thus anterior. Twelve segments are visible, and of these the sixth to twelfth possess little pads with spines which function instead of legs. The mouth opens between two oral lobes with which the anterior end terminates. There are no ocelli, but sensory nerve endings are present on the oral lobes. No mandibles are present, but a black hook-like structure which projects between the oral lobes is used both for locomotion and for tearing food.

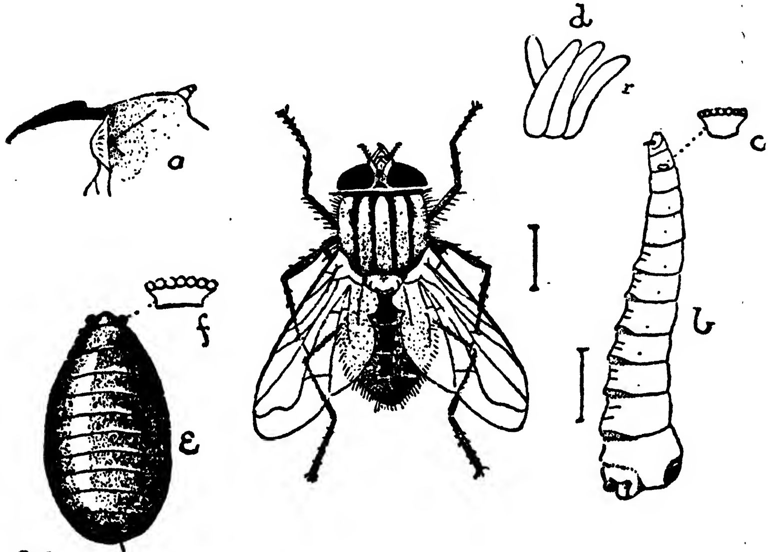


FIG. 203.—Housefly and life history. (From Theobald.)
a, Mandible of larva; *b*, larva; *c*, anterior spiracle of larva; *d*, eggs; *e*, pupa case; *f*, remnants of spiracle on pupa case.

The larva breathes by tracheae, but there are only two pairs of spiracles. One pair is situated on the second segment, the other on the posterior segment. The larva moults twice and the whole larval life may only last five days if the temperature be high. Whilst the larva is feeding and growing it migrates away from light and seeks the moist parts of its food. When, however, it is ready to pupate, it searches out preferably a dry crevice. Arriving at a suitable spot the body contracts somewhat, the anterior segments become telescoped into the others so that a barrel-like shape results and thus, without any moult, the larva becomes the pupa, the last larval skin forming the pupal

case. This gradually turns brown in colour. Within the pupa a very considerable destruction of tissue takes place, most of the larval organs completely disintegrate and from small groups of cells a new set of internal organs is produced. In three or four days the perfect fly is ready to emerge from the pupal case, but in order to get out one end of the case has to be broken away. This is performed by a peculiar sac which protrudes from the head of the fly for this purpose.[1] The sac is afterwards withdrawn, the wings expand and harden and the adult insect, incapable of any further increase in size, is ready to fly off.

It will be noted that, since the larvae live in and feed on filth, there is not only a need for the female to visit this for egg laying, but the newly emerged fly will probably find itself in a filthy spot. The fly's legs and body, being hairy, easily pick up dirt, quite apart from the fact that some of the filth or dirty water may be sucked up by the fly. Thus any visit to an exposed milk basin or to any food which is not protected may easily result in bacteria being left behind. The fly is acting, in fact, just as if one might take a camel's-hair brush, dip it in a culture of disease germs (or in a collection of filthy water, etc.) and then brush it over food stuffs.

It will have been noted that the whole development of the housefly may proceed from egg to imago in nine or ten days. Usually the length of life varies (barring accidents) from a few weeks to the whole summer and autumn seasons, but a few flies probably can and do hibernate and thus survive until the next spring.

Insect metamorphosis

Now the question of the interpretation of insect metamorphosis arises. What is the meaning of such a roundabout development as that of the housefly or butterfly? Can we apply the explanation put forward in the case of the frog, and does the caterpillar or the fly 'maggot' indicate something of the ancestral history of the butterfly and housefly? It would be very dangerous to apply the interpretation of the frog life history here. The fact is that whilst there may be fundamentally a tendency for animals

[1] The sac known as the *Ptilinum* can also be of immediate use to enable a newly emerged fly to push up through two feet of soil to ground surface.

to pass through stages in their development which are reminiscences of their past history, this is often obscured.

It is difficult to explain insect metamorphosis, but we may try with an analogy. The first buildings made by man were small huts and gradually greater and greater structures have been made. In all cases, however, until recently the builders have started from the bottom and worked upwards and a gradual development of a building in this way could be watched and still is to be seen. It has been found suitable, however, in some cases in modern building, to put up a framework of great iron girders and then commence to put on the stonework at the top before it is applied at the bottom. The end result does not suggest that the building has been constructed so differently. Thus we may modify the early stages of building in all kinds of ways, as our knowledge of methods and materials increases, without essentially altering the end result. Probably the ancestors of the insects of to-day had a direct development without metamorphosis, just as we see it in the cockroach and many other of the lower insects. There are two essential needs during the early growth stages—food and oxygen—and it is quite possible that changes in the form and habits of the early stages took place in the course of many generations. The character of the early stages will also depend on the degree of development reached when the egg hatches. So the life history of an insect with a complete Metamorphosis like the Butterfly might be comparable with one having no pupal stage (Hemimetabola), as follows:

Insect with incomplete metamorphosis.		Insect with a complete metamorphosis like Butterfly.
Egg ↓		Egg ↓
Stage I ↓	⟶	Stage I ↓
Stage II ↓	⟶	Stage II
	Egg hatches ⟶	↓
Stage III ↓	⟶	Larva ↓
← Egg hatches here.		Larva ↓
Stage IV ↓ Stage V ↓	⟶	Pupa ↓
Adult	⟶	Adult

Now possibly Stages A and B of the insect ancestor of the butterfly were indications of the actual ancestors of the insects, but the caterpillar and the pupa of the butterfly of to-day are not even indications of Stages A and B. They are highly modified developmental stages which have arisen, we know not how, but which are presumably fitted to their environment.

Other types of metamorphosis

In the case of animals sheltered within the body, or in a protective egg shell, during the whole of development,

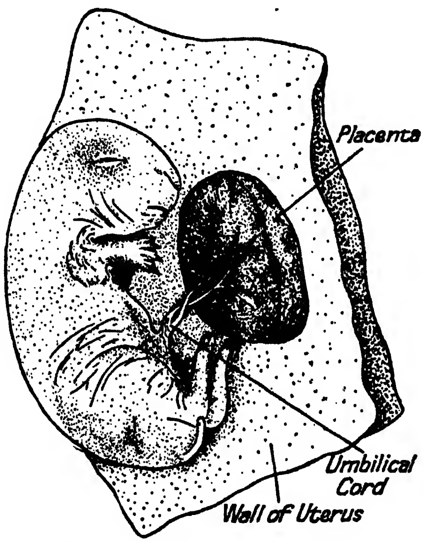


Fig. 206.—Rabbit embryo before birth.

there is not so much likelihood of finding metamorphosis as in examples with a relatively long early stage, but in the former cases the change from the environment of development to that of adult life may necessitate readjustments and even rather sudden structural modifications. A brief review of the later development of a mammal such as the rabbit will serve to illustrate a very different type from those previously considered.

In the preceding chapter, we described the internal fertilisation of the rabbit's egg, the passage of the egg into the uterus where development commenced, and the formation of a structure, the **Placenta**, in which the interchange

between the blood of the embryo and the mother took place. The developing rabbit after the tenth day is surrounded by a membrane, the **Amnion,** which arose from the embryo at an earlier stage. The cavity between this membrane and the embryo becomes filled with fluid so that the embryo is as it were 'cushioned off.' Projecting through the ventral body wall of the embryo are two outgrowths connected with the alimentary canal. One of

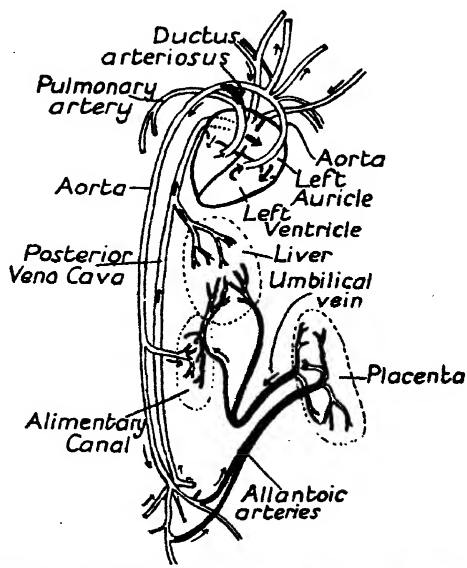


FIG. 207.—Diagram of blood circulation of rabbit embryo (just before birth). For simplicity the smaller vessels are not shown.

Blood vessels which only function in embryo shaded black. (Note the short circuiting of blood through the wall between the two auricles and the short circuit from Pulmo. Art. to Aorta through the Ductus.)

these is in reality a yolk sac, although it never contains yolk; the other is known as the **Allantois.** It is this latter outgrowth which plays the big part in the formation of the placenta. It is richly supplied with blood and is connected with the embryo by a slender stalk (see Fig. 206). Eventually the stalk of the yolk sac and the allantoic stalk become enclosed in membrane and form the **Umbilical Cord** which connects the embryo with the placenta until birth takes place. Along this stalk, conveying blood outwards, to the placenta pass two umbilical arteries which arise from

the dorsal aorta. The pure blood from the placenta is brought back by an umbilical vein.

Changes at birth of mammal

The chief vessels of the embryo rabbit are shown in the sketch (Fig. 207). But this shows that some oxygenated blood is entering the right auricle by the vena cava. In the adult, this vein only brings in deoxygenated blood which the right auricle hands over to the right ventricle, from whence it is forced to the lungs for oxygenation. The lungs, however, although already developed, cannot possibly function owing to the situation of the embryo ; moreover this arterial blood which enters the *right* auricle should really be passed to the body generally by the *left* ventricle. It gets there in a curious way. A small hole is present in the wall between the two auricles and through this the blood coming from the placenta goes, so reaching the left auricle and then the left ventricle. Notwithstanding this, some of the blood entering the right auricle does reach the right ventricle and consequently leaves the heart by way of the pulmonary artery. Again, however, a curious embryonic speciality saves the situation, for a small duct (**Ductus arteriosus**), short-circuits this blood away from the lungs and into the aorta.

We must note, therefore, that just before birth there is a blood circulation in the young rabbit which is different from that of the adult. The lungs have never acted as respiratory organs, no food has ever passed through the mouth opening and the body has been kept at a normal and constant temperature without the use of its own regulatory mechanism. Bearing this in mind, it will be obvious that birth for a mammal means a remarkable change of environment.

At birth the amnion bursts, the young animal is forced to the exterior by the muscles of the uterus wall. It is still attached to the placenta by the long umbilical cord. Finally the placenta comes away from the uterus of the mother and the placental circulation is abruptly stopped. At the same time the uterus of the mother contracts so that the torn blood spaces are closed and bleeding is prevented.

Now regard the newly born animal. The changed environment (possibly the cold air), stimulates respiration, or the stoppage of placental circulation causes the lungs and chest to commence their functions, and with each breath more and more blood passes to the lungs. The ductus arteriosus ceases to short-circuit, whilst at the same time blood pressures prevent the other short cut being taken from the right auricle to the left, and with this the typical adult blood circulation is achieved. The umbilical cord shrivels up, the point where it emerged through the body-wall is always marked by a scar—the navel—in some mammals, but such is not to be seen in the rabbit. The umbilical arteries and veins within the body gradually disappear.

The young rabbit is still unable to look after itself. Its digestive system is only adapted to a milk diet. The eyes, in the case we are considering, are still closed and the skin is without hair. Some mammals are much more advanced at birth (calf).

The human infant at birth has all its organs, but they are not yet perfect in structure or function. The skeleton, for example, is still partly cartilaginous. A period of childhood now ensues which lasts until maturity is reached. Up to the time of birth the normal development of the mammal is largely a question of the health of the mother. After birth, it is a matter of the environment in the widest sense of the word.

Practical work on animal life histories

I. The life histories of the butterfly or silkworm-moth, and of the frog are most easily studied in the laboratory and with the greatest advantage. The eggs of the cabbage white butterfly may be sought for on cabbage leaves in May, June or July, and leaves can be brought into the laboratory. A suitable breeding cage is easily made with black cotton net on wire frame. Keep it in the shade.

The silkworm caterpillars can be purchased from Messrs. Head & Co., Entomologists, Burniston, Near Scarborough. Frog's eggs should be sought for in springtime, but they should not be ruthlessly removed en masse from the ponds and wasted. They may be kept in large rather shallow

vessels. Large pie dishes will do. Another method is to make use of a large porcelain sink in the laboratory, if it be absolutely clean By fixing gauze over the overflow pipe a constant but slow current of water may be kept going. Of course, this means the sink is reserved for several weeks, which may not be convenient.

II. The life history of the housefly should be studied practically if possible, as an example of a household pest of great economic importance. Unfortunately although the animal is such a common pest obtaining the eggs is not so easy. Efforts might be made to obtain eggs by placing a considerable number of flies early in the season in a large glass jar containing moist horse manure and closed at the end with fine gauze. Probably however, it will be necessary to seek the living larvae in waste matter.

III. If an incubator is obtainable, a study of the development of the chick may be made. This, however, entails the use of the microtome and preparation of sections unless a very superficial study is made. It is not worth purchasing an incubator for the latter alone, and it would probably be more profitable to purchase microscopic preparations already made from one of the University Zoological laboratories. The student who wishes to follow up the study of embryology must refer to text-books on the subject.

XVIII

THE FRESH WATER POND AS AN ANIMAL COMMUNITY

THE student of animal biology must not regard any living organism as an independent type, but rather as a member of a community, for no animal is independent of the environment. The life in a fresh water pond, being a small and compact entity, provides us with a very convenient example of a community in which we can not only examine the functional life of the various inhabitants, but can study their behaviour, their relation to one another and to their environment. And although life in a pond is a different thing from life in the streets of an industrial town or that of a tropical forest, there is much that is common. The study of the pond will serve also to take the student out of the laboratory and bring him into direct touch with nature. Indeed, the study of fresh water life is one of the most fascinating branches of our subject, and some of the greatest pioneers in natural history—Leeuwenhoek of Holland and Swammerdam of the same country, Malpighi in Italy and the famous Réaumur of France found material of absorbing interest in it.

Water as the external medium

The outstanding difference between the pond and the two other associations referred to above is naturally the presence of water as the external medium instead of air, and this implies in the first place a difference in the arrangements for obtaining oxygen. Two possibilities are at hand —one that the pond animals should breathe air directly, like their terrestrial relatives, and should rise to the surface or above it to obtain this air; the other possibility is to have respiratory organs capable of abstracting dissolved air from the water. But the presence of water bathing the surface of the body also implies differences in locomotion

(floating and swimming structures are desirable), and it brings with it other physical and chemical relationships with the environment.

In temperate regions like our own, there is a great chance that the water of a pond will be converted into ice in the winter. Consequently the pond animals might be expected to have some means of withstanding this unfavourable season, and we should expect to find a seasonal rhythm in our pond association, just as there is in a terrestrial community in a district with marked seasons. In some parts of the world the risk is not that of freezing in winter, but of the pond drying up in summer. We should expect adaptations to meet this danger also.

The Pond, as we understand it, is one of those small collections of water commonly scattered about the fields of this country in contrast, on the one hand, to lakes like those of the English Lake District or Loch Lomond and others in Scotland where the water is deep, and on the other hand to the great comparatively shallow expanses of water like Lough Neagh in Ireland or the meres in various parts of Great Britain. A sharp distinction is impossible and the same thing applies to the fauna, but we may note that seasonal changes in physical conditions will not be so marked in the large lakes as in the small ponds, where the temperature variations of summer and winter will be greater and where the quality of the water is likely to be very different according to whether there has been much rain or great evaporation.

It is essential for the study of the life of a fresh water pond that many visits be made. In fact, we suggest that very interesting original observations may be made by visits to a group of ponds every two weeks or so during a year, if both the physical conditions and the animal life be kept under continuous observation in this way. The apparatus required is of the simplest and should be adapted to capturing microscopic organisms floating in the water as well as organisms living in the mud at the bottom and amongst reeds or other plant growths (see end of chapter).

We may divide the organisms into the **Plankton** (floating organisms which can live independently of the bottom and possess no organs of locomotion or such as would scarcely render their possessors independent of even slow currents in the water) and the **Benthos** (animals living on the **Types of pond life**

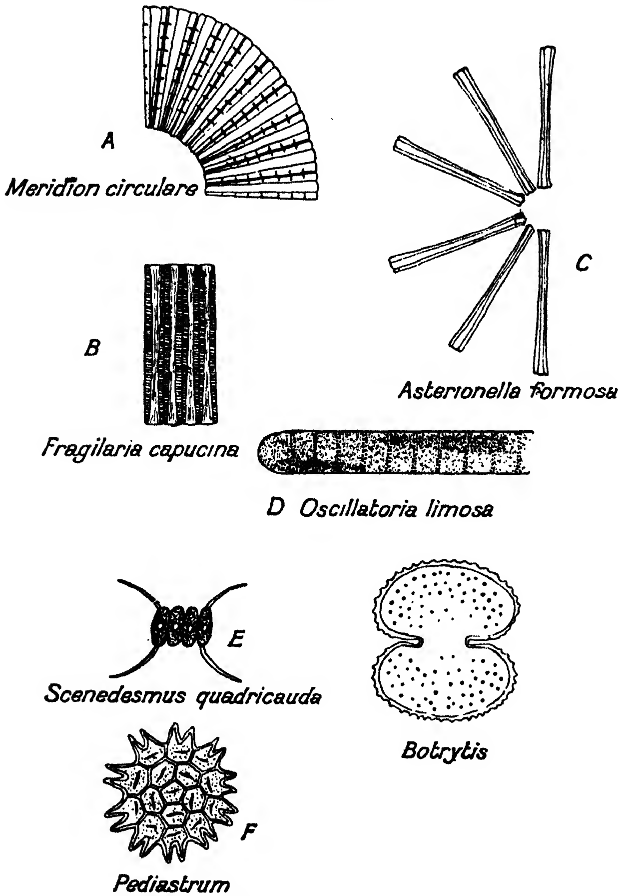


FIG. 208.—Some pond diatoms and desmids, etc. (After West.)

bottom, attached or crawling), and we then have left those creatures like the fishes and certain insects which move actively and definitely in the water, at times resting, on the bottom or in amidst the weeds, at other times visiting the surface. These swimming creatures make up the community known as the **Nekton.**

Some Characteristic Types.

Pond vegetation

Before turning to the animal side, it is necessary to point out the importance of the plants in the pond community. We shall find that there are very lowly plants—the blue-green algae—most of which are microscopic and which abound in the floating association of organisms that we have called the plankton. Sometimes when the heat is great in summer, such tremendous reproduction of these blue-green algae takes place that the surface layer of the pond may be a thick scum consisting of millions of these organisms. This feature is, however, perhaps more common on certain English meres (in Cheshire) than on ponds. Other blue-green algae live on rocks, stones, submerged tree trunks, etc. Other floating microscopic plants belong to the lowly group of the **Diatoms.** These plants are characterised by the possession of a shell (often beautifully sculptured) of silica. Another important group of microscopic plants of the pond is the **Desmids.** Members of all three groups will be captured if a fine net of bolting silk is drawn carefully to and fro through the water and then turned inside out in a jar of water.

Apart from these microscopic floating algae, there are the much larger floating plants of the highest group—the flowering plants—and there are various other aquatic plants free or attached to the bottom. The pond plants have for convenience been grouped as follows:

I. Plants without attachment:
   (*a*) Floating microscopic forms—plankton.
   (*b*) Large forms like duckweed (Lemna) and filamentous algae.

II. Plants attached to substratum:
   (*a*) Submerged algae—Chara and Cladophora.
   (*b*) Submerged flowering plants—Vallisneria and Elodea.
   (*c*) Partially submerged flowering plants—Nymphaea.

III. Swamp or marsh plants with roots and lower stems under water and upper parts above the surface.

To us, however, the plant community is interesting in its relation to the animals. The plants, both microscopic floating, as well as large attached forms, are the producers and they stand in the same relation to the animal life of the pond as the grasses of the fields to the herbivorous animals which subsist on them.

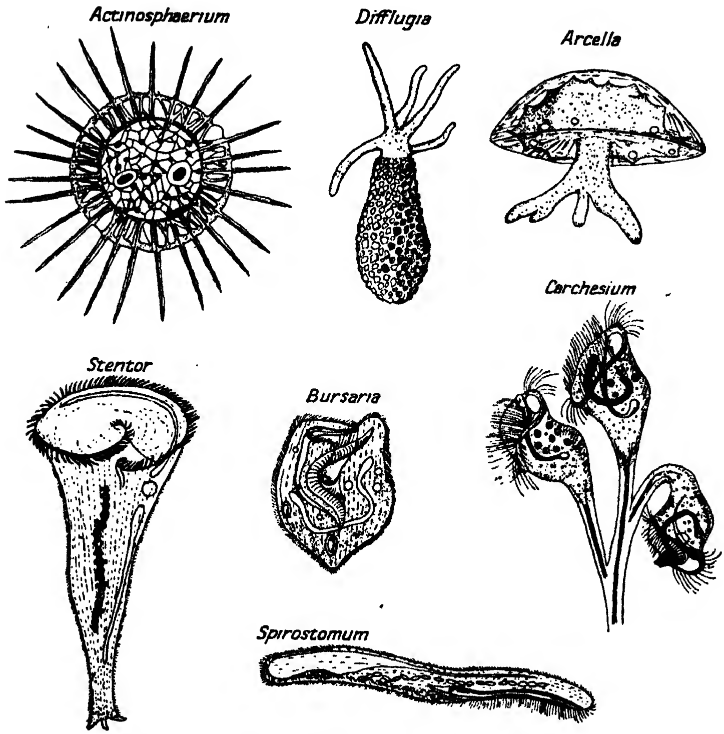


FIG. 209.—Some pond protozoa.

The Pond Animals.

Perhaps the outstanding character is given to pond life by the Crustacea, but many other animal groups are represented either in adult or larval stages. A few of the more common types likely to be met with are enumerated and illustrated in the following pages.

Among the **Protozoa** are naked and shelled forms, floating forms and species found crawling on the surface of the mud of the bottom or on submerged leaves. All **Pond protozoa**

these should be sought for. Submerged decaying leaves should be brought back to the laboratory and kept in dishes. Samples of mud from the bottom should be similarly treated.

Amoebae (see Fig. 2) of various species may be found in the mud and on decaying leaves and in moss. Related to these are the shelled forms, *Difflugia* and *Arcella* (Fig. 209). The first makes a shell of sand grains or other particles of dirt, whilst *Arcella* secretes a brown horny shell. Belonging to another group of Protozoa—the Heliozoa—are *Actinophys* and *Actinosphaerium*, characteristic floating forms. Both are moderately large as Protozoa go, especially the latter, which looks like a little milk-white or opalescent

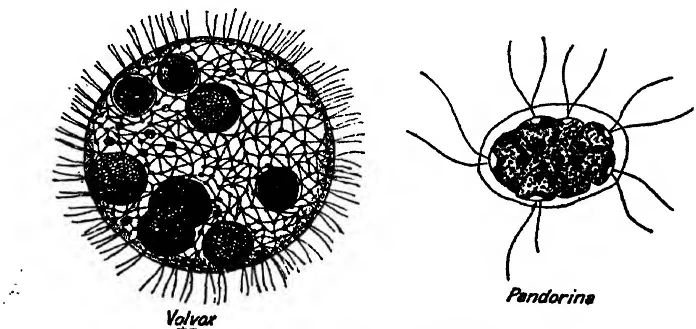


FIG. 210.—*Volvox* and *Pandorina.*

sphere floating in the water. The pseudopodia are unbranched fine radiating processes in both examples (commonly termed sun-animalcules).

Representatives of the Flagellata should be common, ranging from the small colourless forms like the Monads, to Euglena (see Fig. 11) and the colonial flagellates like *Pandorina*, *Eudorina* and *Volvox* (Fig. 210). There may also be Dinoflagellates like *Ceratium.*

Related to *Paramecium* (Fig. 4) are the ciliates—*Frontonia*, *Spirostomum*, *Bursaria* and *Stentor.* The latter may be swimming about, but is most often attached by its narrow end to leaves, etc. *Vorticella* is another common attached ciliate, as well as the very similar *Carchesium* and *Epistylis.* On the gills of the Crustacean *Gammarus*, one may find the attached protozoon *Dendrocometes.*

The green plant-like flagellates manufacture their food from the mineral salts and raw materials present in the pond water. They are producers like the green plants of the field. They become the food of the animals either in

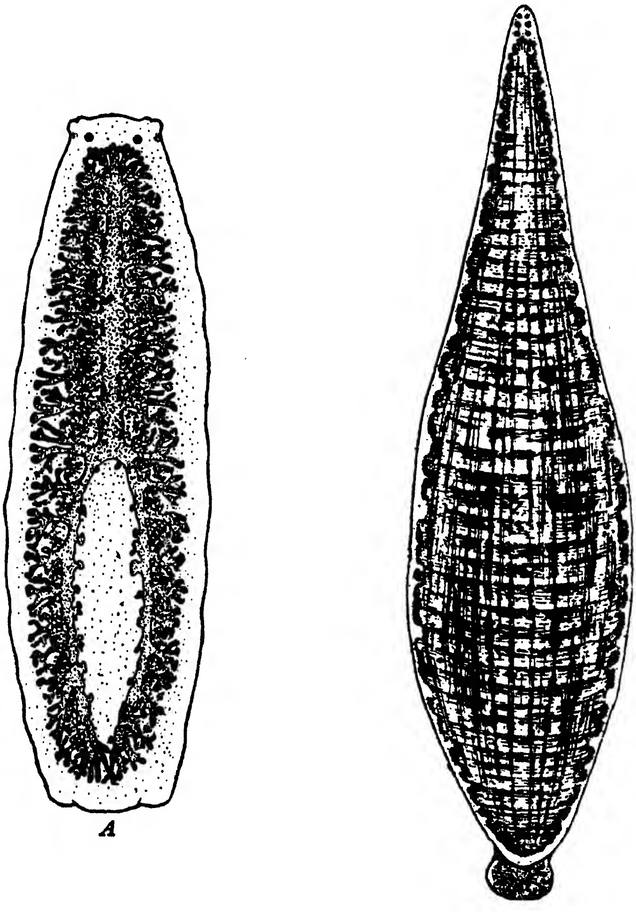


FIG. 211.—A pond Turbellarian (*A*), and a leech (*B*).

the living state or in the form of debris. *Amoeba* and its relatives feed on quite large algal cells. The ciliates often make more use of bacteria.

Hydra should be found attached to submerged water plants. We have dealt elsewhere with its feeding habits, **Hydra**

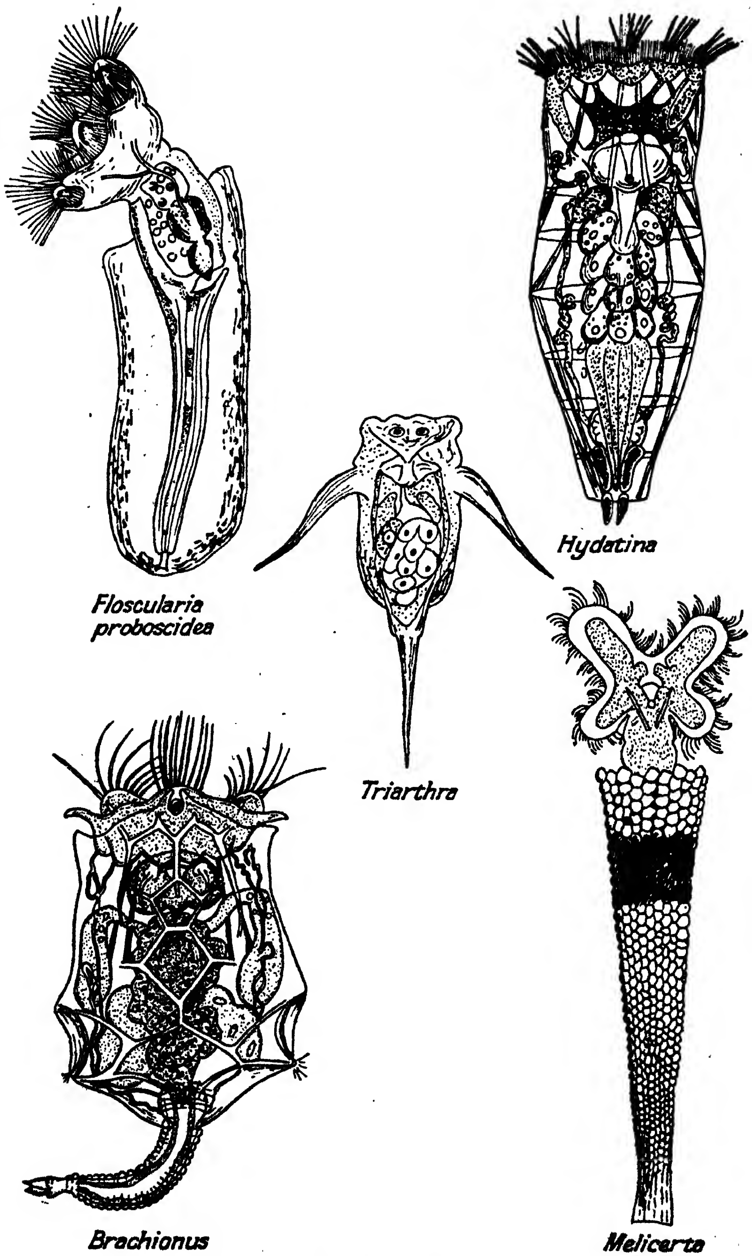


FIG. 212. Some common Rotifera.

its locomotion, etc. It is most abundant in the early months of summer.

Flat worms

Several interesting flat worms—*Turbellaria*—are common in ponds. Sometimes they may be seen gliding along in full view. They should be sought on the under side of stones and amidst vegetation. These animals are closely related to those remarkable and common parasites to be described later (Chapter XIX), the liver fluke of sheep and the tape-worm of man and domestic animals. They may

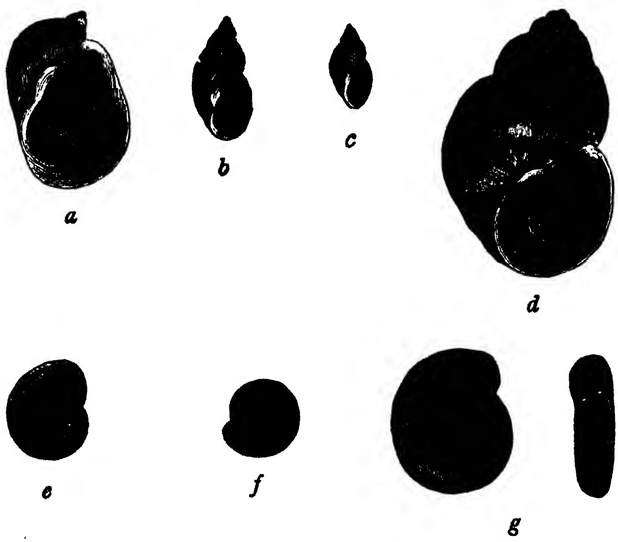


Fig. 213.—Some common pond univalves. (From Furneaux.)
a. Limnæa auricularia. *b.* Limnæa palustris. *c.* Limnæa truncatula. *d.* Viviparus viviparus. *e.* Planorbis albus. *f.* Planorbis vortex. *g.* Planorbis complanatus.

be mistaken for leeches at first, but their slow forward gliding movement without any apparent organs of locomotion is characteristic. They move by means of cilia. Many experiments on regeneration may be made with these worms, for they have great powers of regenerating lost parts—pieces which have been cut off, for example.

Rotifera

The Rotifera, often known as Wheel Animalcules, are common and characteristic animals of the ponds. Although microscopic, they are highly developed in structure, there being a true body cavity and alimentary canal with

mouth and anus. Food, which consists of other microscopic floating organisms, is collected by a circlet of cilia on the disc at the free end. Most rotifers are free swimming, the ciliated disc being the locomotory organ; others are to be found attached to plants. Both kinds may build up or secrete a shell. A few common species are illustrated, for example, *Hydatina, Triartha, Brachionus, Floscularia* and *Melicerta*.

Pond molluscs Fresh water Mollusca, both univalves and bivalves, are common in ponds and we should find the pond snails—*Limnaea* species—amongst the weeds or even crawling at the surface (see below). The pond snail has to crawl up weeds to the surface for air and it easily floats if its pulmonary chamber is full of air; it can sink quickly to the bottom by suddenly withdrawing into its shell and forcing out the air from this chamber. *Limnaea stagnalis* passes the winter in a state of hibernation buried in the mud at the bottom of the pond.

Another common pond univalve is *Planorbis*, of which several species may be found. *Physa* and *Ancylus* may also be easily recognised.

All the above are air breathers, and this would indicate that they have been evolved from terrestrial species which had been quite adapted to a life on land. There are pond univalves, however, which have developed gills—*Viviparus*.

All the pond snails are vegetarian, scraping away the plant tissues with their file-like ribbon of teeth. They are themselves the prey of birds, frogs and toads and even of the larvae of the water beetle (*Dytiscus*).

The eggs of these molluscs are laid in little jelly masses which may often be found adhering to leaves or stems.

Of bivalves there may possibly be the large fresh water mussel—*Anodon*—half buried in the mud of the pond. These shellfish feed, like the salt water mussel, on the microscopic organisms and debris which they draw into their shells with the current of water set up by the cilia on the gills. Their life history is astonishing. The eggs are retained after fertilisation within the gills until they become tiny little bivalves, but of a very different form from

their parent. These, however, do not grow up directly into adults. They attach themselves and become for a time parasitic on fishes. After a stage inside a little cyst or gall on a fish, which stage lasts some weeks or longer, the mussels now with their typical form drop off and fall to the bottom.

Pond insects

The insect group belongs essentially to the air and the land and practically no member lives below the surface of the sea. A small number of species have, however, become adapted to a fresh water life and many others have early stages which are aquatic. This is a remarkable feature, for all show by their respiratory organs that they have been derived from air-breathing terrestrial forms. Many aquatic insects are compelled to obtain air directly for respiration—they are not adapted for obtaining it wholly or even in part from the supply in solution in the water. Others have well developed gills in various positions on the body. The study of aquatic insects is made particularly interesting because of the remarkable adaptations for life under water—a medium for which we should have expected the insects to be most unsuited. One might add that on the whole this is the case, although a few forms are so much at home in it.

Another feature of interest is that among the insects with aquatic early stages is the mosquito, which is so notorious now as a disease carrier that the destruction of the larval stages has become a factor of great economic importance in some countries.

Amongst the insects whose early aquatic stages are found in ponds, reference may be made to the Mayfly whose **Nymphs** (early stages) spend two or three years in the water, living in the surface layer of the mud at the bottom, but swimming about when disturbed, and whose adult aerial life is but a matter of a few hours. This brief winged existence is devoted to the mating and the laying of eggs. The nymphs, in the case of the mayfly, have developed gills but, notwithstanding this, they possess the typical insect respiratory organs—tracheae—and branches of these run into the gills (see page 118).

The dragonfly is another well-known insect which has aquatic early stages. The method of respiration has been discussed on page 119. Dragonfly nymphs are very active and very voracious. They are amongst the greatest marauders of the pond. For the purpose of capturing their live animal prey a curious structure, the **Mask,** is developed.

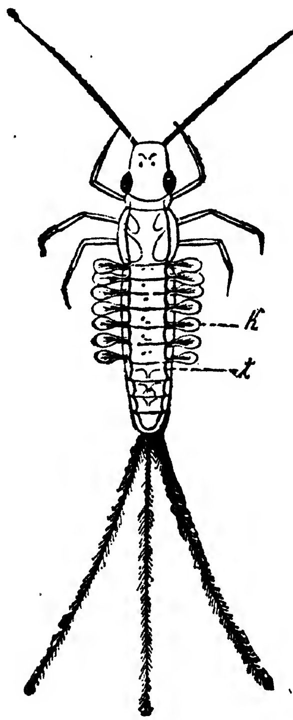


Fig. 214.—Nymph of mayfly. (From Sedgwick.)
***K*, tracheal gills; *t*, principal trachea.**

It is really an enlarged labium (see Fig. 215), and it masks the other mouth parts. The metamorphosis of the dragonfly is particularly interesting and can be easily followed in aquaria if a good supply of nymphs are collected and kept well fed with tadpoles.

The illustration of the larva and pupa of the **Mosquito** should enable one to recognise these stages. The larva is often transparent enough to allow of the internal anatomy being easily observed in the living specimen. The tracheae

and the breathing organ (Siphon) should be made out and also the feeding brushes (bunches of hairs which are rotated rapidly for collecting food), the alimentary canal, the eyes and nerves, etc. Note that the opening of the respiratory

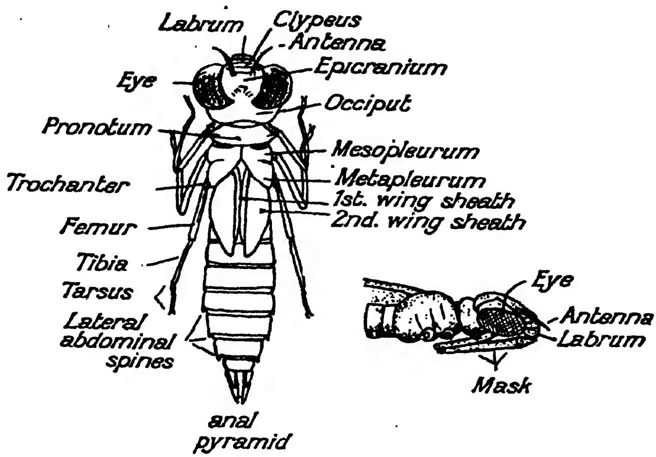


FIG. 215.—Full-grown nymph of a dragonfly Aeschna. *A*, Dorsal. *B*, Side view of head. (After Tillyard.)

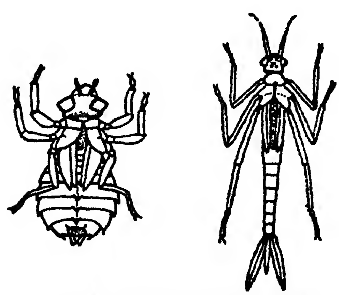


FIG. 216 —Nymphs of dragonflies.

tube of the larva is at the end of the abdomen, whilst the pupa obtains air at the surface by means of two projecting tubes from the cephalothorax.

Other adults and young stages of aquatic insects can be recognised from Figs. 221, 222, etc.[1]

[1] For detailed accounts of the life histories and habits, etc., of aquatic insects, see Miall's *Aquatic Insects*, Introduction to Zoology by Lulham, and Ward & Whipple's *Fresh Water Biology*.

Pond crustacea Probably the most common animals of the pond will be species of the Crustacea *Daphnia*, *Moina*, *Simocephalus*, *Bosmina* (Water fleas), *Cyclops* and *Diaptomus* (Copepoda) and *Cypris*. These are mainly found floating and swimming as constituents of the plankton. They are well deserving of study, for not only can most of the organs of *Daphnia*, for example, be made out in the living specimens without injury to them, but one can observe such features as peristaltic movement in the intestine (see page 80), one can time the heart beat and note its relation to temperature (page 146) and, lastly, there are endless opportunities for experiments on reproduction (page 365)

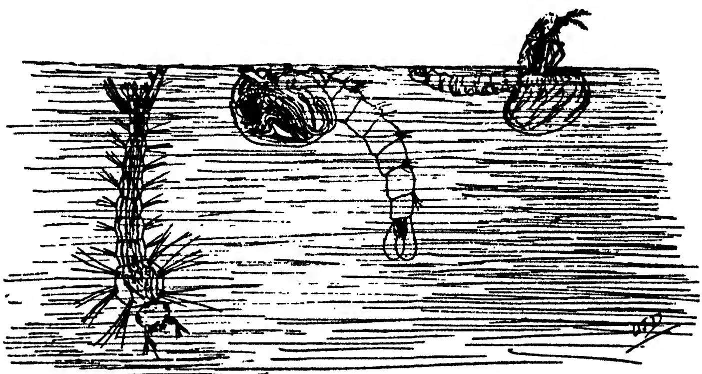


FIG. 217.—Life history of a mosquito (*Culex*).

and heredity, which can be made with the simplest of apparatus.

Other pond creatures to be noted are the leeches, Fig. 211, the aquatic earth-worms and the Bryozoa (attached colonial organisms, superficially like branched Hydras, but really animals of much higher organisation).

We shall now consider some of the features which may be studied in this fresh water animal community. The various members have each their own type of habitat in the pond. They may crawl on the mud, live in the mud protected by small cases secreted or built of sand grains, **Flotation** attach themselves to weeds, or float almost constantly in the water. This floating habit is the most characteristic feature of the collection of organisms we have called the

plankton. The organisms may be lighter than the water they displace, somewhere about the same weight (and this is probably the usual condition), or they may be heavier. There are several methods of reducing the specific gravity. *Arcella* and *Difflugia* secrete gas vacuoles at times within the protoplasm, the phantom larva (Fig. 221, *Corethra* larva) possesses two pairs of air sacs which possibly act as hydrostatic organs for flotation. Other forms secrete oil globules or gelatinous sheaths for the same purpose, as for example many Crustacea. One of the most characteristic developments, however, for this purpose is the extension

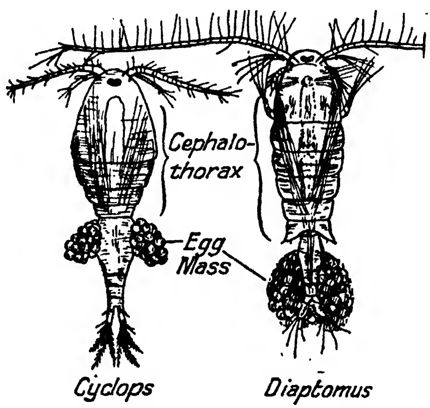


FIG. 218.—*Cyclops* and *Diaptomus*.

of the outer surface of the body in the form of spines or long outgrowths. The long radiating pseudopodia of *Actinosphaerium* probably aid in this way, and the feature is most clearly seen in the Rotifera and the Crustacea, where the appendages are often fringed with long processes.

Other planktonic creatures, which are about the same specific weight as their environment or are heavier, raise themselves by active swimming movements. The water fleas use their second pair of antennae as swimming organs; the Copepoda use their first pair of antennae for this purpose.

In this connection mention must be made of the **Surface Film.** If a clean steel needle is lowered carefully on to the surface of water in a tumbler it will float, although

The surface film

many times heavier than water. If, however, it breaks through the surface ever so little, it sinks rapidly. The needle is held up by the surface film of water, the particles of which are in a peculiar condition, the result of what is known as surface tension. They cohere together to form a film, and this presents a resistance to the passage of an object through it. The fact is, that the surface of water where it is in contact with air, is in a state of tension or pull. This may be demonstrated by a little experiment suggested by Miall. A small square is made by taking two ordinary matches for two opposite sides, and their ends are connected with cotton thread for the other two sides.

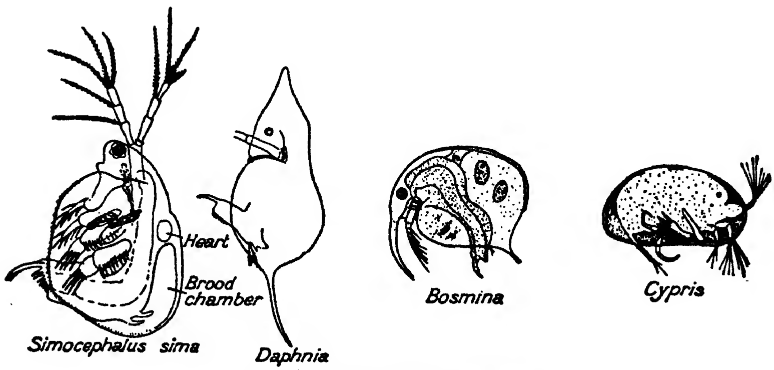


FIG. 219. Some pond Crustacea.

A needle pushed through one match makes a handle. If the square is dipped in a strong soap solution of the kind used for blowing bubbles, a film of soapy water will occupy the space when it is lifted out. Notice, however, that the threads are curved inwards owing to the pull of the film.

As the late Professor Miall so ably pointed out, this surface film is both useful and dangerous to pond animals. The pond snail can crawl on the 'under' surface of a surface film as if it were a piece of glass. The pond skaters glide over its upper surface. Various insect larvae have to pierce it to obtain their air supply, and whilst obtaining it they are held, supported by this layer, without effort. An excellent example of this is provided by the larva of the gnat or mosquito. In this case there is an interesting

contrivance at the end of the siphon which not only closes it, but reduces the surface contact to a minimum when the larva wishes to descend. Small aquatic creatures, however, may be trapped and held altogether by the surface film if they should break through it. Daphnia have been known to perish in numbers in this way.

Competition for food in pond community

The pond animal community provides us with an excellent example of the struggle for food, and there must be a regular cycle of events every season as one source of food becomes available and then in turn is used up. Our pond community consists, as we have seen, of producers and consumers. Raw materials for plant food are available in the

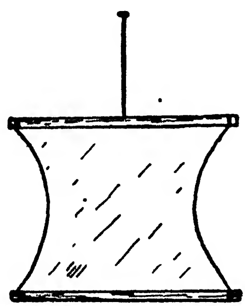


FIG. 220.—Method of illustrating pull of surface films.

water which contains gases dissolved from the air—oxygen, nitrogen and carbon di-oxide—as well as substances derived from the mud or soil of the pond bottom and the surroundings which drain into the pond. In addition, substances are constantly being added by the life and the decay of both animals and plants. As a general rule raw material, in particular nitrogenous matter, will be rather plentiful in the pond water, especially when compared with well water and with river water. As a result we may expect a greater abundance of organisms, and these will be in such a measure adapted to the constitution of the water that it is often necessary to set up experimental aquaria with water from the same pond as the organisms which are to be studied.

The raw materials—mineral salts, nitrogenous matter, carbon di-oxide and, of course, the water—will be built up

into complex food stuffs by the green organisms. These are mainly the plants, both large and fixed, as well as the microscopic floating Diatoms and Desmids. Some Protozoa also contain chlorophyll—for example, Volvox and Euglena (these are often regarded as plants for this reason); they will also be producers. In addition, there will probably be an extensive population of bacteria in the pond water, living on dissolved organic matter. These must also be regarded as producers. The animals, small and large,

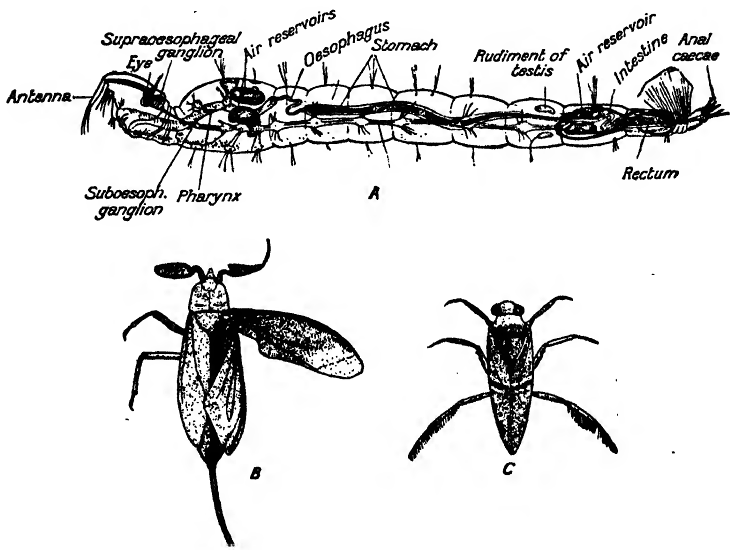


FIG. 221.
A Corethra (after Weissman) × 11. *B*, Nepa, × 2·5. *C*, Notonecta, × 3.

are the consumers. They are dependent upon the organisms just enumerated. The larger ones feed on the smaller and so on. Every organism has its own characteristic food. Many of the Protozoa feed on the bacteria. The small Crustacea (the water fleas and Copepoda) feed upon the microscopic plants and also upon the Protozoa. The Crustacea in their turn are devoured by certain fishes. Most of the insect larvae probably feed directly on the microscopic plants of the plankton and the mud of the pond bottom or on the organic debris contained in the latter, but some of the larger vicious forms, like the larva

of Dytiscus and the dragonfly nymphs, feed on other insect larvae, on worms and larger animals such as tadpoles and even small fish.

All the possible modes of nutrition are met with in the pond community. Those animals which hunt the larger organisms, or capture microscopic creatures by filtering the water and digest the animals or plants so obtained, are

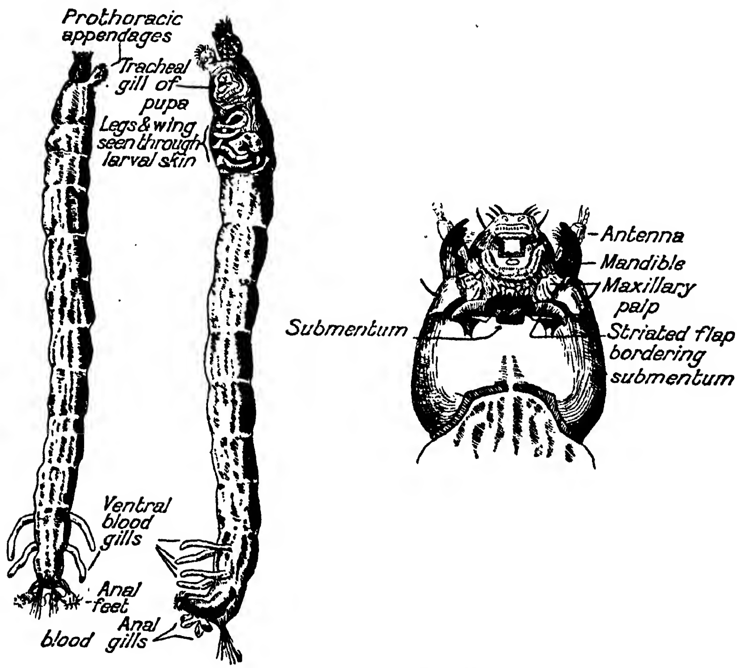


FIG. 222.—Larvae of *Chironomus*.
A, Half grown. *B*, Full grown. *C*, Ventral surface of head. (After Miall.)

Holozoic feeders. The bacteria, and probably certain of the Protozoa, feed upon organic matter in solution, even *Euglena* obtains most of its food by absorption, and this mode of nutrition is not uncommon amongst Protozoa. *Paramecium* containing green cells, the Dinoflagellates and certain other flagellates with green plastids, and the green Hydra probably obtain part of their food supplies from raw materials, rather like green plant cells. The floating green plants are, as we showed above, typical plants in so far as their nutrition is concerned.

Parasites are also present in the community, that is, animals which live on or in the bodies of other living animals. Ectoparasitic [1] Protozoa (*Trichodina* and *Kerona*), allied to *Paramecium*, will probably be found on the outer surface of *Hydras*. Ectoparasitic flatworms may be found on the gills of fresh water fish. Parasitic roundworms (or thread worms) are certain to be present. They are not ringed nor do they bear setae like the aquatic earthworms. Some of these worms are free-living throughout their life, others are to be found in the bodies of the pond insects and Crustacea, and they are often very common in the frog. Then in the pond snail one will probably find the parasitic early stages of the 'liver fluke,' a parasitic flatworm, the adult stage of which inhabits the liver of sheep.

The cycle of life in the pond

In contrast to a patch of desert we have in the pond all the conditions necessary for the sustenance of life. Energy from the sun falls upon the patch of desert, and as a result the ground is warmed up. This heat is lost at night—the sun's energy is wasted. The lack of water prevents the existence of living things which might store up the sun's energy and render it available to man. The presence of pure water in a rocky basin might not be very different, for there would be practically neither plant food nor animal food. But even in such a spot as this organic matter may be blown in and bacteria or their spores carried in the dust, and gradually living organisms would appear.

The pond, however, is a very favourable collection of water, even in the beginning. The water drains in from the surrounding fields, bringing salts and nitrogenous substances in solution, and plant life commences to develop. Probably the microscopic plants appear before the larger fixed forms; they have resistant stages which withstand dryness, and are blown about in this condition and distributed everywhere. With the development of plant food, animal life increases in abundance. The smaller forms have probably been brought in with the water, or they may have been blown in by the wind in encysted conditions. Larger species may reach the pond attached to the feet of birds

[1] Ectoparasites are parasites on the *exterior* of the animals.

or in various accidental ways until eventually we have the crowded community that is usual in ponds of years' standing. But in this community, as in a big town, the animals are constantly producing waste matter, and death results in the constant addition of animal bodies to the water. These waste matters would eventually choke up the pond and bring all life to an end were it not for a further step. We often look upon the bacteria solely as enemies of man, as agents of disease. There are, however, many extremely useful bacteria, and certain of these are responsible for the breaking down and the change of deleterious waste

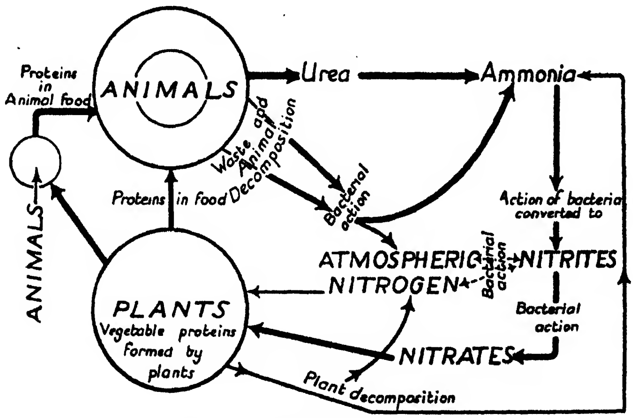


FIG. 223.—The nitrogen cycle.

nitrogenous substances (the excreta of animals) and the carcasses of animals into simple substances like nitrates. The result of the action of these bacteria is the preparation of certain very important food stuffs for the green organisms, which again build up the more complex organic substances so necessary as animal food. With this there is a complete cycle in the pond.

The nitrogen cycle

Because of the great economic importance of the nitrogen compounds, this cycle is of exceptional interest to us. We have seen (Chapter IV) that these compounds are essential for plant and animal life on the earth, and although plant and animal life has existed for many millions of years, there is no accumulation of nitrogenous substances in our

ponds, seas, or in general on the solid ground. From the water, the soil and the air they are taken, and after forming part of the structure of plants and animals they return whence they came to be used up over and over again.

The higher green plants make use of nitrates and ammonia as their sources of nitrogen, and they transform these substances into amino-acids, amides, and eventually to proteins. These are devoured by animals, and in modified form take part in the construction of their bodies. When waste nitrogenous substances are excreted or the animal dies, these nitrogenous compounds are broken up by various kinds of bacteria until ultimately simple stable substances are again reached, like nitrates and nitrites, ammonia and even free nitrogen. Other bacteria may build up ammonia and nitrogen into proteins again, or into nitrites and nitrates; the green plant utilises the latter, and so the cycle goes on.

Seasonal changes A very short study of pond life will show that there is a seasonal change in this community which is as marked as the fall of the leaf in autumn and the opening of the buds in spring. The coldest winter months are the barren periods of the year, especially if frost occurs. (It is, however, surprising how much may still be found during the winter months. December may still show abundant life in the pond; January, February and March are probably the lean months.) Summer time is the period of luxurious growth. But there are various cycles—each organism has its own period of maximum abundance and its own season of reproduction. These maxima are dependent upon (*a*) the chemical composition of the water, which varies throughout the year, (*b*) the temperature, (*c*) the food stuffs available, (*d*) the interaction of the different organisms, and (*e*) a possible inherent physiological rhythm. A great deal is known of the succession of the organisms in the marine plankton, and some investigations have been made in Europe and America on the succession of life in the bigger lakes.

It will probably be found that the microscopic plants undergo a minimum during January, February and March,

and that a gradual increase then begins, with different periods of maxima for the different groups and even the different species. The animals will be found to decrease in a similar fashion from November onwards, but the advent of spring and its stimulus to the plant development will be followed by an increase in the animal groups with maxima in spring, summer and autumn.

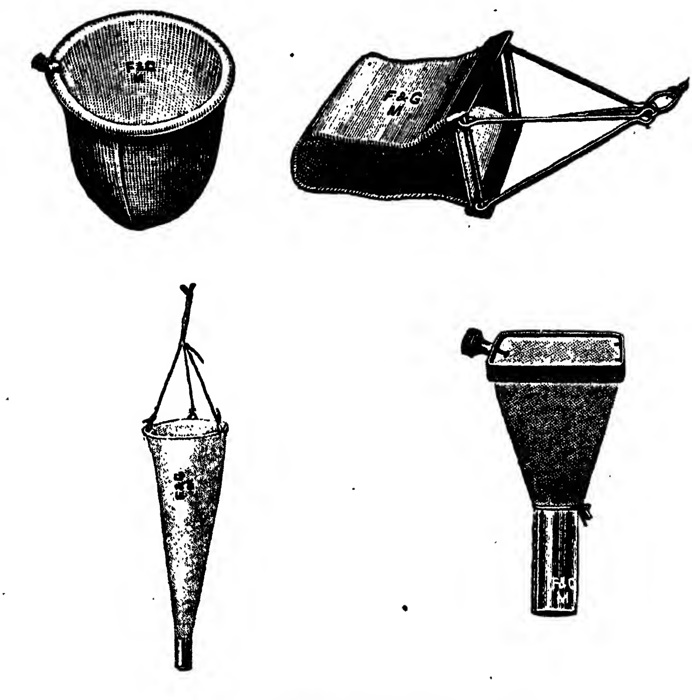


Fig. 224.—Nets and apparatus for pond life.

Practical work on pond life

Practical work on pond life should be carried out over a long period. It should form a background to other work and supply organisms which are often needed when studying functions or structures. The work should not only include a series of collecting expeditions to ponds for the purpose of (1) obtaining material, (2) noting the seasonal changes which are taking place, but should include the setting up of small aquaria in the laboratory.

The apparatus required is the following:

1. A net of fine bolting silk supported on a square frame about four to six inches square, and preferably with an open end to which a small glass vessel is attached. The frame should bear a screw socket, to which a stick may be attached. Suitable instruments are sold by Flatters and Garnett of Manchester, but they can easily be made.

2. A net of coarse canvas attached to a stronger frame than the above (and about one foot across). This should have an attachment of some kind to a stout stick or pole, so that it can be used for scraping through the rushes.

3. A piece of white waterproof cloth about two feet six inches square which can be spread on the ground. The catches made with the big net, consisting of leaves and water weed containing molluscs and insects, should be spread out on this white background, and it is then easy to pick out the spoil. This is a particularly useful accessory.

4. Tubes will be required to bring home the smaller specimens, and jam jars or, much better, aluminium or enamel pails with lids (the Australian 'billy'—made in England, but not so frequently exposed for sale here and not under the Australian name). These may be used also for bringing back the glass tubes.

5. A small grappling iron made by soldering together three or four large meat hooks is useful. It is to be attached to a long cord, and can be used for pulling in submerged plants or roots, etc.

6. Where large ponds or meres are at hand a large silk tow net may be made and pulled after a rowing boat. These nets are usually conical bags with the mouth attached to a circular galvanised iron ring about one foot in diameter. The net is made about 2 feet 6 inches long. The material used is fine bolting silk (used for sifting flour). No. 20 is most useful.

XIX

SYMBIOSIS, COMMENSALISM, PARASITISM

In the section on Nutrition we considered the feeding habits of animals which lead a free life, and one might almost say the kind of life which is typical of animals. The competition or struggle for existence in the animal world is so keen, however, that practically no possible environment is without some adapted creatures. The dark abysses of the ocean are tenanted, the high slopes of Mount Everest, the Arctic regions, and even desert places and hot springs. It is not surprising therefore that we should find many species of animals which have developed the convenient, but often degrading habit of living on or in the bodies of other living animals.

An association of two animals in which one gains its livelihood at the expense of the other is known as **Parasitism.** The animal which is robbed or devoured is known as the Host, and the robber is termed the Parasite. There are other associations, in which one animal lives on or in another, but which must not be confused with Parasitism.

It is possible to have two species of animals or an animal and a plant living together for mutual benefit. This association is known as **Symbiosis.** The green bodies in the cells of green *Hydra* are symbiotic plants. They may obtain nitrogenous food stuff from the *Hydra*, whose cells they in return supply with oxygen and carbohydrates and keep free from certain waste substances. Another example which may be cited is the occurrence of certain sea anemones on shells in which hermit crabs live (Fig. 225). The crab is protected by the anemone, and it is believed that the anemone is better provided with food as the result of possessing a means of locomotion. **Symbiosis**

Commensalism

Another type of association is one in which the partners do no harm to each other, but only one reaps any benefit. This is generally called **Commensalism** (Messmatism). Possibly some cases are symbiotic, and as a matter of fact it is often difficult to distinguish between the two, for the distinction depends on a knowledge of the nutritive habits and physiology of each animal concerned. Typical examples of commensalism are those in which a crab lives in the cavities of a sponge. Other examples are found amongst certain microscopic animals—Protozoa—which

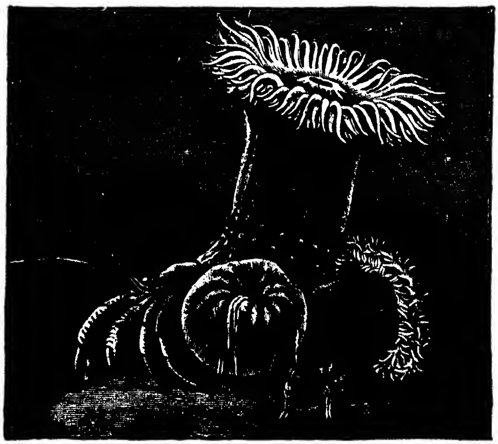


FIG. 225.—Sea anemones on shell of hermit crab. (From Borradaile.)

live in the intestines of the higher animals and feed on the waste matter, doing at the same time no harm to their host. It is not a very far cry from this type of association to that of parasitism, in which the one animal feeds upon the tissues or the food supplies of the other, and in addition often poisons its host with waste matters of an extremely noxious kind.

Parasitism

Parasites are found in almost every group of animals. Some of them live on the outside of their host, and are known as external parasites (**Ectoparasites**). Others live only within the body, and generally within some particular organ. These are **Endoparasites.** And in very many cases, such is the intimate relation of parasite and host,

we find that one particular species of parasite is adapted to some particular host, and is not found on or in any other animal.

Some parasites again (and this applies more to the ectoparasites) can leave their hosts and for a time lead a free existence. These temporary or **Facultative Parasites** are not so dependent as the permanently parasitic forms, and are not so highly modified. And here we touch one of the

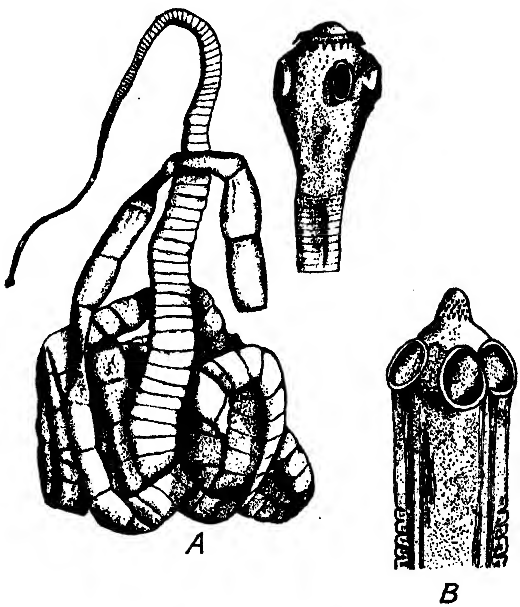


FIG. 226.—The tape-worm.
A. *Taenia solium*. *B*. Head of *Dipylidium caninum* from cat.

most interesting features of parasitic organisms. They have become modified—adapted to meet the peculiar features of their existence. Let us illustrate this by reference to one of the most highly modified and extreme cases—the tape-worm. Tape-worms are ribbon-like creatures which **Tape-worms** are found living in the alimentary canals of vertebrates. Two species are common in man, *Taenia solium* and *Taenia saginata* (more so in some countries than in the British Islands). Tape-worms are also quite common in the sheep, dog, cat and other domestic animals, and one of these forms

could easily be obtained for examination. *Moniezia*, which is common in the sheep, is probably most easily obtained, but usually without its head. *Dipylidium*, the tape-worm of the cat, is therefore perhaps the best to take. (See Fig. 226 for differences between *Taenia solium* and *Dipylidium*.)

The tape-worm consists of a minute head followed by a thread-like portion which gradually expands into a ribbon of segments called **Proglottides.** The head bears suckers and hooks for attachment to the host. There is, however, no mouth opening, and no obvious sensory structures are to be seen.

Parasites, and in particular endoparasites, have both shelter and ample supplies of food at their disposal. They are thus free from an ever present danger of enemies and relieved of the necessity of detecting food and catching it. Keeping this in view, it is interesting to find that parasites generally show a reduction (one might say a degeneration) in the sense organs and the organs of locomotion. On the other hand, the necessity for remaining in some particular part of a host demands organs for attachment, and hooks, suckers or other structures are developed. All these points are well illustrated in the tape-worm, which is an extreme example of parasitism. It lies in the intestine with its head buried in the mucous membrane. The hooks and suckers serve to keep it in position. There are no eyes and no organs of locomotion, although movements take place in the worm owing to muscular contractions and relaxations.

The worm is, of course, actually immersed in partly digested food. This is absorbed through its outer wall; it lacks not only the mouth, but alimentary canal, special organs of digestion and all organs for the capture and prehension of food.

One might naturally ask why the tape-worm and other worm parasites of the intestine do not become digested, seeing that animal tissues are dissolved by the digestive juices in the human intestine. The explanation is that these parasites whilst alive actually produce secretions which render their tissues immune to the digestive juices surrounding them. An experiment to show this has already

been described on page 93. Substances which neutralise the chemical action of the digestive ferments in this way may be termed **Anti-ferments.** Their production is probably common to all organisms, commensals as well as parasites, which inhabit alimentary tracts where digestive ferments are found.

Ecto-parasites

Having studied an example of extreme parasitism, we may glance at two of the much less modified ectoparasites. Most ectoparasites of the mammals and birds (and thus of man and of his domestic animals) belong to the group Insecta and the related group Arachnida. They comprise the fleas, biting and sucking lice, and the ticks.

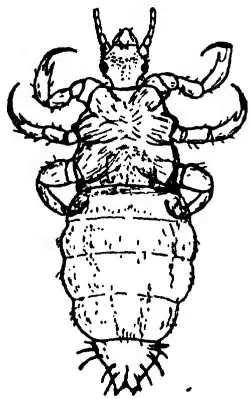


FIG. 227.—The louse.

The louse

The human body louse, of which there are two races, one race being found between the hairs of the head, the other on the clothing next the skin, is generally only present under dirty conditions and should be easily controlled. It may become excessively abundant under conditions of camp life, as it did in the Great War. The insect is small and wingless, and has a pair of eyes. It has mouth parts adapted for the special purposes of piercing the skin and sucking blood. They form a little flexible proboscis. Another special adaptation is found in the legs which are constructed for climbing and grasping hairs. Each ends in a single claw, which hinges back against the next preceding joint of the leg (like the blade of a clasp knife) and is shaped to fit around a hair.

Thus we note again adaptations for holding on and for feeding, whilst reductions have taken place in locomotory organs (the wings) and in the sense organs. This ectoparasite exhibits nothing like the specialisation of the tapeworm.

The flea The flea (*Pulex irritans*) agrees with the louse in that it has no wings (we know that the ancestors of both the louse and the flea had wings), and although it has eyes, the compound eyes so characteristic of insects are absent. The mouth parts are adapted for piercing the skin and sucking blood, but their structure is not the same as those of the louse. Beyond these resemblances these ectoparasites are quite different, and indeed belong to separate insect groups.

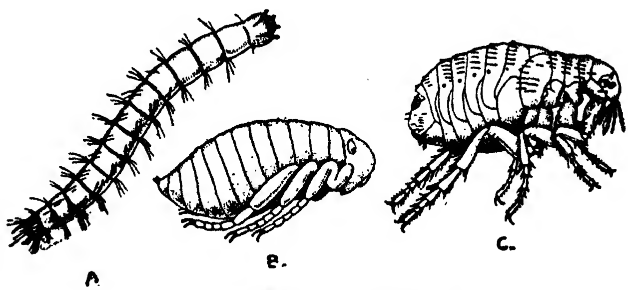


FIG. 228.—The flea. (From Borradaile.)
A. larva; *B.* pupa; *C.* adult.

The most characteristic adaptation of the flea is its compressed shape. It seems most suitable for movement amidst the close hair on the body of a mammal. The parasitic specialisation of the fleas is such that different species are associated with different hosts. Thus the cat flea is not the same as the dog flea, and both are different from the human flea. This adaptation is, however, not so close as to prevent altogether the animals leaving their real host and moving and feeding on another species.

Now between the degrees of parasitism illustrated by the types described briefly above, there are all grades. Besides ectoparasites which can leave their host and go to another, like the flea, there are others which are much modified, and cannot exist apart from their hosts. Endoparasites in their final and mature stage are usually confined to their hosts.

They may live in the blood, in the intestines, in cavities of different organs of the body, or actually within cells.

In practice an excellent idea of some of the different endoparasitic types may be obtained by a careful examination of the frogs used for dissection. It is quite a successful method where large numbers are being used, as in school and university laboratories. Details of certain of these parasites are given below under the heading of practical work and in the Appendix.

Practical work

I. For an example of Symbiosis green *Hydra* should be examined under the microscope and the green cells in the endoderm cells observed (see Fig. 38).

II. Specimens of hermit crab in shell covered by an anemone should be seen in a museum collection.

III. If many mussels are examined, specimens will probably be found harbouring little pea crabs. Another commensal often occurs in the large fresh-water mussel.

IV. Sheep tape-worms. *Moniezia* can often be obtained from abattoirs. It may be difficult, however, to find one with the head. Mounted specimens of *Taenia solium* should be bought, or efforts made to obtain *Dipylidium* from the cat. If fresh material is obtained, the worms should be fixed in formalin (5%) for some hours, and then after washing in water, over-stained slowly (two or three days) in very dilute Ehrlich's haematoxylin. The stain should next be extracted just as slowly in alcohol containing just a trace of acid. This treatment should render the internal organs of the segments visible when cleared in benzol and mounted in canada balsam (see page 459). Slight pressure on a series of proglottides whilst fixation is taking place will make the segments less thick, and therefore more transparent afterwards. (Place them between two glass slides tied together with thread.)

V. Examine under microscope both a human flea and a dog flea, and compare their shape and general structure with that of a louse. Note absence of wings in each case and the different manner in which the flea and the louse are flattened (that is, flea compressed from side to side, louse from above downwards). Note any differences between

the fleas from the two hosts; they are likely to be different species.

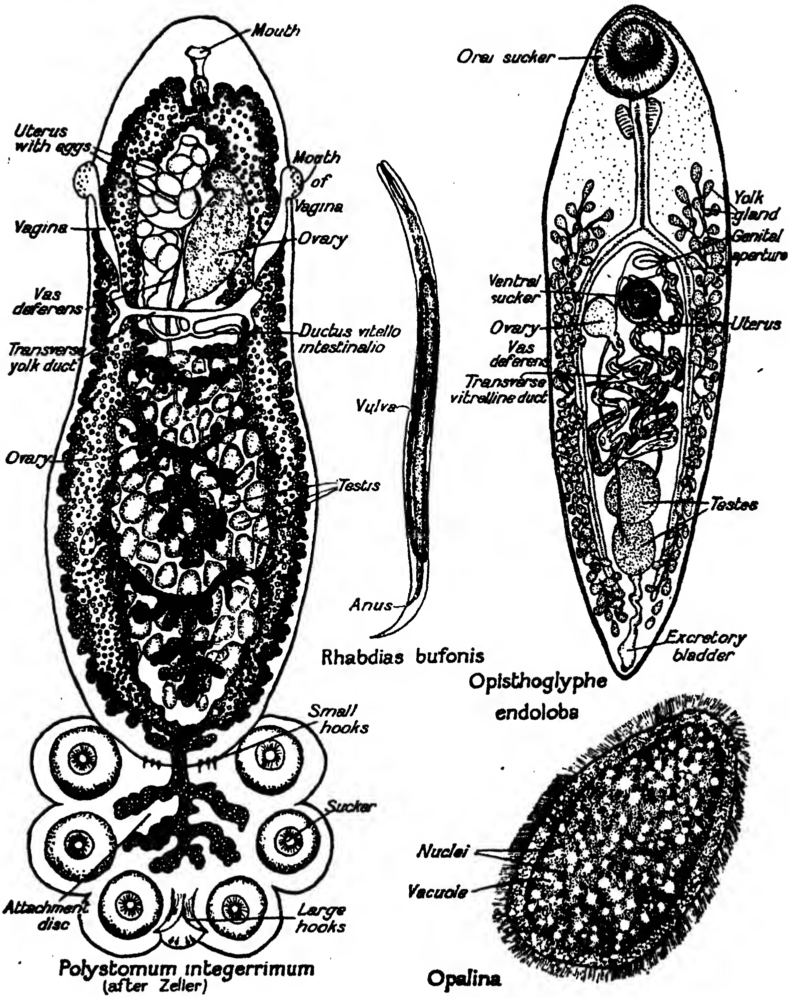


FIG. 229.—Parasites from the frog.

VI. Carefully search frogs used for dissection, or opened specially for the purpose, for parasites. Protozoa are commonly found in the intestine, and include *Opalina* (a ciliate related to *Paramecium*), *Balantidium* and *Nyctotherus*. Sometimes a *Trypanosome* may be found in the blood.

Trematode worms may be found in the lungs, the bladder and the intestine. They include *Polystomum integerrimum* (from the bladder), with six suckers at its posterior end, and *Opisthioglyphe endoloba* (from the intestine), which shows up its internal anatomy particularly well if examined in the fresh condition. The trematodes usually lie close to the intestinal wall. If the faeces are pushed out and the intestine laid in salt solution and cut open, the worms can be brushed into the fluid with a small camel's hair brush.

Thread-worms—Nematodes—are very frequently found in the lungs (*Rhabdias bufonis*, once called *Angiostomum nigrovenosum*, is a common species).

The contents of the intestine should be examined in a little salt solution (0·75% common salt in distilled water) for the protozoa. The flatworms should be carefully picked out of the intestine and bladder, placed on a slide in a drop of salt solution and squeezed slightly under the weight of a cover slip. After drawing and making out as much of the anatomy as possible, the specimens may be fixed in hot 70% alcohol, hardened in 90%, then stained and made into permanent preparations. These parasites are illustrated in Fig. 229.

XX

THE REPRODUCTION AND LIFE HISTORY OF PARASITES. DISEASE

In the above section we have referred to certain aspects of parasites without touching upon their methods of reproduction or distribution. These features of parasitic organisms are so interesting that they are most conveniently treated separately.

In the matter of nutrition the parasite appears to be at an advantage, when compared with the free-living animal which has to seek and capture food, and is thus often brought into competition and warfare with other animals. It pays for this advantage, in that it is exposed to danger of death if its host dies, either as the result of the parasite (see under) or from some other cause. Also the parasite has to overcome the serious difficulty of introducing its offspring into the correct host.

The simplest life histories are presented by the less modified temporary ectoparasites which, like the flea, can leave their host. The reproduction of these animals is straightforward. The flea lays its eggs amidst the hairs of its host or on the ground or bedding, where the latter lives. In the first case they drop off to the ground, where they hatch and give rise to larvae, which are minute worm-like creatures. The larvae (human flea) feed on substances in the dust in crevices of floors, etc., and after various moults extending over a few days they spin cocoons and the larvae pupate. When the adult stage emerges, it seeks its proper host. This life history is quite a typical insect life history, and no very special modifications caused by the parasitic life are presented.

Permanent parasites present very different life histories. Roughly, we mav say there are two types. In the one

there is some stage which is resistant and leaves the host or is shed from it, and is eventually picked up by another host of the same kind. In the other type there are intermediate hosts, which not only carry certain stages of the development, but are absolutely necessary for the complete life cycle of the parasite. The tape-worm is a parasite of the latter kind, which has two hosts, and it will serve as an example of this indirect development.

Life history of tape-worms

The chances that the offspring of a tape-worm will reach the alimentary canal of another host are very slight. These risks are counterbalanced by a tremendous development of the reproductive organs. It has been calculated that a *Taenia saginata* could emit 150 million eggs in a year. This fecundity is a very characteristic feature of parasites. In the tape-worm not only is the animal hermaphrodite (see page 343), but there is a complete set of reproductive organs in each proglottid). After the tape-worm has attained its full size, terminal proglottides are periodically dropped off (the size of the animal remains constant, because new proglottides are constantly being formed at the neck region), and these are practically nothing but bags of fertilised eggs. If the tape-worm is *Taenia solium* of man, no further development of the eggs can take place unless they are swallowed by a pig. This animal may happen to pick up one of the dropped proglottides whole, thus swallowing hundreds of eggs, or if the proglottid decays in the ground the eggs are scattered, They may retain capacity for life for a long time, until eventually they may be picked up with the food. In either case the digestive juices in the stomach of the pig act on the egg shells, which really enclose little embryos, for the eggs were fertilised inside the tape-worm before their shells were secreted round them. The embryos are released, but although delicate they are not digested. On the contrary, they appear stimulated and commence actively boring through the alimentary canal wall into the blood and lymph vessels. Then they pass in the blood stream to the connective tissue of muscles all over the body. Here they are arrested and pass through various stages

with increase in size (see Fig. 230) until at the end of three or four months a stage known as the **Cysticercus** is reached. It is one of the most extraordinary things in this life history that the Cysticercus stage cannot progress further unless it is eaten by a human being. It remains dormant in the pig's muscles, and nothing else happens unless the pig be killed, the flesh distributed as human food and eventually eaten. The Cysticerci can just be distinguished in the flesh by the naked eye. Badly infected pork would be recognised and condemned by public health officials if they saw it, but odd infections might escape this inspection. Thorough cooking would, of course,

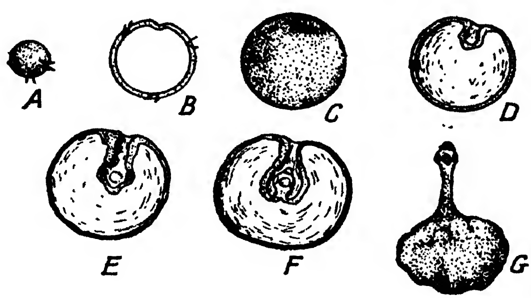


FIG. 230.—Stages in life history of the tape-worm.
A. Embryo. *B-F*. Stages in development of Cysticercus. *G*. Cysticercus with head evaginated.

kill these Cysticerci, but sometimes pork is used in an uncooked or half-cooked state, especially in some parts of Europe. In any case, if a living Cysticercus should enter the human intestine, it is stimulated to further development. The head burrows into the wall of the alimentary canal, and proglottides are produced until a long tape-worm results; the bladder part is lost.

The whole story reads like a fairy tale, and it is difficult to realise how an animal species could be dependent for its continued existence on the vicissitudes which must occur in this life cycle. It is no wonder that millions of eggs must be produced to ensure even a few adult tape-worms.

Many life histories of parasites are of a similar nature, some are actually more complex. The complicated

succession of stages are all parts of an effort to ensure passage from host to host.

The following other examples of human parasites may be mentioned, although details are omitted : **Some parasites on man**

The life cycle of the parasitic protozoan causing Malaria in man has been described (page 36). Two hosts are necessary in this life cycle. A few serious diseases in man are caused by trematodes, one of these, Schistosoma (common in Egypt and other parts of Africa, etc.), is found in the portal blood vessels. The intermediate stages of its life cycle are passed in pond snails.

FIG. 231.—Caterpillar and larvae of a parasitic insect which have just emerged from it.

There are several other tape-worms which may occur in man with intermediate stages in other animals, such as the ox, cat and dog. It is therefore inadvisable to allow children to kiss and fondle the two latter animals or to play about with their feeding utensils !

Thread-worms, like the hook-worms and Ascaris, are common in man, particularly in some parts of the world. These do not have two hosts in their life cycle.

Amongst interesting ectoparasites may be mentioned the highly modified Crustacea which are found on the gills of fishes. The common flounder is very often affected in this way, and so is the whiting. The parasites are easily found on the gills if these fish are examined.

Polystomum of the frog, in its early life, is ectoparasitic on the external gills of tadpoles.

Many very interesting parasites are met with amongst the insects. Some of these are parasitic on plants. Others are parasitic on animals, and of these many (such as the bot flies with larvae parasitic in the stomach of the horse and in the head passages of the sheep) cause serious losses amongst our domestic animals. A few insect parasites may be put down on the credit side of our account against the army of deleterious insects, for certain species deposit their eggs inside the eggs or larvae of some of the destructive insects, and thus keep in check some of the most injurious plant pests (Fig. 231).

THE EFFECTS OF PARASITES ON THEIR HOSTS

The modifications of parasites are so remarkable that one is not surprised to find that parasitisation does not necessarily mean death, or sometimes even inconvenience, to the host. As a matter of fact the death of the host would often be a disaster for the parasite. Where parasitisation is extremely deadly to the host, we often regard the infection as a recent one, because there is a tendency for hosts to become adapted to their parasites, or even immune and antagonistic to them. During past ages many host races have established an equilibrium with highly organised parasites. This is particularly the case as the result of bacterial invasion (see below).

Parasites may cause trouble to their hosts in the following manner:

(*a*) By robbing their food supply directly or indirectly. Alimentary canal parasites, if numerous, do this.

(*b*) By poisoning, due to the excretory matter of the parasite. This is the case in the malaria parasite and the parasite causing sleeping sickness. Probably tape-worms and other intestinal parasites also cause trouble in this way.

(*c*) By mechanically destroying tissues, and in this way often leading to other infections. The hooks of the tape-

worm probably tear the alimentary canal wall. Other parasites bore their way about the tissues of the body.

(*d*) By destroying tissues as the result of feeding on them.

(*e*) By blocking up passages. Worm parasites often do this.

(*f*) By causing changes in the tissues in which they live, *e.g.* cysts, galls in plants.

This discussion of parasitism, and especially its effects on the host, naturally leads to the problem of animal disease. We speak of a creature as diseased when its functions are not proceeding in a normal manner. The diseased condition may be due to the improper functioning of one part of the body only—one organ or a small group of cells—or it may be general. General unfitness often follows local disturbance, for we have seen that there is a remarkable co-ordination between all the tissues of the body, and it is easy to see how the abnormal functioning of one organ may affect the rest. The causes of disease may be roughly classified as follows :

(1) Disease arising out of some inherited structural defects or deficiency.

(2) The improper use of the organs of the body or the deleterious effect of an abnormal environment. This includes :

Over eating or drinking.
Bad food, preserved food or no food at all.
Working with poisonous substances.
Accidents of all kinds, etc., etc.

(3) *The invasion of the body by parasites.*

We have already referred to the effects of some animal parasites on their hosts. The response of the host is very clearly shown by reference to certain other parasitic organisms, which unfortunately are responsible for much disease and are found everywhere in nature. They are known as Bacteria. They are the smallest of all living things, and are generally regarded as the simplest and classed as lowly plants. A brief account of the Bacteria is appended here, because in the first place there is no absolute reason for

considering them as either plants or animals, and in the second place they have been studied largely owing to their invasion of the animal body and their effect upon it.

BACTERIA

The study of bacteria is usually regarded as difficult for junior students, chiefly because very powerful microscopes are needed to observe them. This is true, but the effects of their presence can easily be demonstrated, and whilst we may not see individual bacteria we can often see them quite easily when they are present in crowds or colonies.

There is little to be said here about their form or structure. Under a high magnification, we find that there are only a few types—little spheres, little rods and rather longer rods or threads with a spiral turn. Yet, by reason of the effects produced by bacteria, we know that there are many kinds of each of these types. Their average size ranges from $\frac{1}{1000}$th to $\frac{1}{50000}$th of an inch, but they make up for their lack of size by their abundance and their powers of reproduction. They are not like typical plant cells—they have no green chlorophyll, and consequently they generally feed on organic matter, living or dead. Their mode of nutrition is usually definite and characteristic.

Practical work on bacteria

In order to perform a few experiments with bacteria, a little special apparatus is required. This consists of some test-tubes, a number of flat glass dishes used generally for bacteriological work and known as Petri dishes, a steam steriliser (a little ingenuity would probably render this unnecessary—a large deep pan with some sort of stand, or fish kettle with the tray raised on legs, to hold Petri dishes, etc., above the boiling water, would do for simple tests), cotton wool, 1 c.c. pipettes and red litmus paper.

It is first necessary to prepare a culture medium. This can be bought ready made and, of course, sterilised, but it may be prepared as follows. Place 1,000 c.c. of water in a pan (preferably a double pan of the porridge-making type) and add to it 100 grammes of gelatine in small pieces, also 10 grammes of peptone and 5 grammes of Liebig's

extract of beef. Heat carefully till the gelatine is melted (stir so that it does not stick to the bottom and burn). Boil for a few minutes and test with litmus paper. Add carefully with the pipette drop by drop dilute solution of Caustic Soda till the mixture just turns red litmus blue. Now filter the hot gelatine solution through a large coarse filter paper or through a funnel lined with wet absorbent cotton. This filtering is not very simple, because the gelatine solution must be kept melted. It is best to place the whole thing in a warm oven and to have the glass funnel warmed to begin with. Run the filtered medium into the test-tubes, about two inches of it in each, and plug each one with cotton wool. It is now necessary to sterilise the

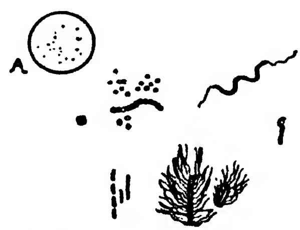


FIG. 232.—Diagram showing relative size of bacteria and different types of bacteria. × about 1000.
A = Mammalian blood corpuscle.

medium. This is done by placing the tubes in the steam steriliser (or the large pan, potato steamer or other contrivance) and heating them in the steam for twenty minutes on three successive days. Any bacteria in the form of resistant spores which survive the first boiling will be likely to have entered the non-sporing form during the following 24 hours, for our nutrient jelly is a favourable medium for their development. They are killed therefore on the second boiling. The third sterilisation is an additional safeguard. The tubes may now be kept without fear of any growths taking place so long as the cotton-wool plugs are not removed.

Sterilise half a dozen Petri dishes. This is better carried out by heating them (lids on!) in a dry steriliser at a temperature of 160° C. for an hour. If a chemical laboratory is

at hand, this is easily carried out in a hot-air chamber. If not, an ordinary oven might be tried. Melt the gelatine in six test-tubes by placing them in hot water. Dry the outside of the tubes and then, taking one, carefully extract the cotton-wool plug with the left hand (hold the tube inclined), and raising the lid of a cool Petri dish with the same hand, run in the gelatine and replace the lid. Do this for the other dishes. The following tests may now be made :

Test I.—Uncover a Petri dish and leave the medium thus exposed to the air for five minutes. Replace the cover and put the dish in a warm place (a cupboard near hot-water pipes—temperature not to go above 70° F.) for 24 hours. For control put another Petri dish of gelatine with this one, but do not uncover it. After 24 hours the surface of the gelatine in the Petri dish which has been exposed should be covered with little dots or even small discs of matter. These are colonies of bacteria which have each grown from one bacterium which has fallen on the surface. The colonies differ in colour or consistency, showing that different species of bacteria are present. No bacteria should be visible in the control dish, if the work of sterilisation has been carried out properly.

Test II.—Repeat the experiment, exposing one dish for five minutes in a room before sweeping and another for five minutes in a room immediately after sweeping. One might be exposed in a schoolroom in the early morning and another at the end of an afternoon. Always allow the same time of exposure. Incubate as before in the warm cupboard for 24 hours to two or three days.

Test III.—Bacteria in water. Melt the gelatine in a number of test-tubes and cool slightly, taking care the gelatine does not reach the solidifying point. Add to one tube 1 c.c. of tap water, to another 1 c.c. of water from a puddle, to another 1 c.c. of water from a cistern. After mixing in each case, and before solidification takes place, pour the contents of each into a sterilised Petri dish as before. Incubate the dishes in the warm cupboard for two or three days and compare the number of colonies.

Test IV.—To show bacteria in milk. Plaee 100 c.c. of

tap water in a flask in the steamer and sterilise in steam for an hour. Allow to cool, and then add 1 c.c. of the milk to be tested. Shake thoroughly. Melt the gelatine medium in one of the test-tubes and add a drop of the diluted milk. Pour the mixture into a sterile Petri dish, cover, and incubate for 24 hours to three days. Note the number of colonies which develop. This indicates the number of bacteria in one drop of the diluted milk.

These experiments may easily be extended.

Bacteria are found almost everywhere, and they are of the greatest importance, not only in human life, but to the continued existence of life on the earth. Some of them are responsible for much evil and disease, but it must not be forgotten that others are almost necessary. Diphtheria, consumption, lockjaw, typhoid fever (to mention only a few diseases) are due to bacteria living as parasites. The ruination of foodstuffs kept too long, especially in warm weather, is due largely to the growth in them and on them of bacteria. On the other hand, the decay of dead animal and plant substances, which would otherwise litter up the earth's surface, and the setting free of nitrogen, are due to the action of bacteria (see page 411), and bacteria in the soil play an important part in the feeding of many green plants. The flavour and quality of butter and cheese is largely dependent on the kinds of bacteria present or allowed to be present.

Yet notwithstanding their importance and widespread occurrence, the bacteria were almost unknown before the work of Pasteur and Koch about the years 1870-1875. Their minute size probably accounts for this. It is not always easy to isolate bacteria even when the results of their existence are fairly obvious.

Reproduction of bacteria

A knowledge of the simple methods of reproduction explains the danger of bacterial infection, and the way in which it can often be prevented when it is undesirable. The bacteria reproduce without any sexual processes, and generally by simply dividing into two when fully grown. This, however, may take place in the short period of twenty minutes or half an hour. Let us suppose that we started

with one bacterium and that all the progeny had equally favourable conditions of existence. At the end of two hours there would be sixteen, at the end of 10 hours 1,000,000, and at the end of a day roughly 270,000,000,000,000! This accounts for the colonies being visible to the naked eye on our plate cultures. It also accounts for the remarkable speed with which food can putrefy on a moist summer day. Of course, the number given above is never reached at the end of 24 hours. That would be a huge volume. If no reduction of this speed of multiplication took place, the earth would very soon be uninhabitable. The rate of reproduction is soon reduced by the presence of the substances which are given off as waste. Not only this, but there is soon a lack of food due to the enormous numbers occupying a confined area.

The widespread distribution of bacteria is a result of their powers of resistance. We have seen that a temperature of 100° C. kills them if they are exposed to it sufficiently long. However, some of them can withstand the lowest temperatures known to us. Cold in any case stops their multiplication and activity, and hence the use of cold storage, freezing meat for preservation, and so on. Mutton in the frozen state can be brought the long six or seven weeks' voyage from New Zealand, and even then kept some time before sale, and is quite good food. Bacteria are probably on this meat, but they are simply dormant. Few bacteria can withstand being dried up, but this danger may be surmounted by **Spore Formation.** Under certain circumstances some bacteria rearrange their cell contents (usually into a somewhat spherical or oval mass) and surround this with a highly resistant wall. The body so produced is known as a spore, and it is extremely resistant to drying up and even to high temperatures (boiling for an hour) which would kill bacteria in the active state. It is owing to spore formation that it is often very difficult to sterilise foods, etc., without adding deleterious chemicals, or altering their constitution by too much heating.

Practical work on bacteria (*cont.*)

Tests to determine the conditions favourable for bacterial growth may be carried out with the simplest of equipment.

Test I.—Take four test-tubes of ordinary fresh milk and plug with cotton wool. Place one tube on ice or in a very cold place. Keep another one at room temperature. Place the third in a beaker of water and raise the water to 60°-80° C. for twenty minutes. Cool and place at the side of the second. Place the fourth tube also in a beaker of water, but raise the water to boiling point for five minutes. Note the different speed with which the tubes of milk go sour, an indication of the extent of bacterial development. Tubes 3 and 4 serve to indicate methods for reducing the danger from milk being contaminated with disease germs. Boiling kills all but a few spores. It is objected to in daily life, because it not only alters the flavour but it destroys vitamins. The 60°-80° C. treatment is known as Pasteurisation. It kills many but not all the bacteria. Spores, especially those of putrefaction bacteria, survive.

Test II.—Add to each one of five tubes of sterile melted gelatine medium a drop of water that is known to be infected with bacteria (it can be taken from a beaker of water which has been standing exposed to the air and which contains a little organic matter of some kind). Place one in sunlight at room temperature, another in the dark at room temperature, to the third add two drops of carbolic acid and keep in the dark in a warm place, to the fourth add a little boracic acid solution; the fifth may be used as a control and placed in the dark with the third.

Note that sunlight is detrimental to the growth of bacteria, and that the boracic acid and carbolic acid also prevent growth. Substances of this kind are sometimes used as food preservatives in the dilute state. It is most probable that they are deleterious to human health, and certainly are not good in children's food. Chemicals which are suitable for the rapid destruction of bacteria are used as disinfectants.

Test III.—Melt the gelatine medium in a test-tube and pour it into a Petri dish. Cover and allow to cool and solidify. Put a fly under the lid or encourage a fly to walk across the surface of the gelatine (the summer or early autumn season will be the only ones in which this can be

carried out in this country). Cover and place in the warm cupboard in the dark for two days. Note the development of bacterial colonies.

Bacteria and disease

Diseases like tuberculosis, typhoid fever, diphtheria and lockjaw, as well as blood poisoning from a wound, are caused by bacteria living as parasites in the human body. In all these cases the very serious effects on the host are not due so much to the bacteria feeding on the tissues of the host invaded as to the poisonous substances (toxins) produced. Although these may be produced at only one spot where the bacteria are confined, they can be carried to all parts of the body in the blood stream.

Disease-producing bacteria enter the body in different ways—through the nostrils or mouth as we breathe, through the alimentary canal with food and drink, through abrasions or breakages of the skin. Consumption or tuberculosis is the result of a specific bacterium, which may enter as we breathe or by way of the mouth in food. The diphtheria bacterium enters in the same way. Typhoid enters with food or drink, but the lockjaw bacterium only produces the effect when it enters by a wound (a pin prick may suffice).

Whilst, however, bacteria are almost everywhere, they are by no means all of this disease-producing kind. Germs of tuberculosis may be very common in the air and dust of crowded cities, more especially in shops and small rooms, and are practically unavoidable, but typhoid germs should not be found in our food unless there has been some definite contamination, and this implies some link, either with people actually suffering from typhoid or at least harbouring the germs. Infected water supplies, due to waste matter (sewage, etc.) getting into wells or other sources of drinking water, may be responsible. Very often, however, the contamination is due to the housefly, which not only passes its early stages in filth likely to be infected, but which visits the same sources to lay its eggs. The bacteria may be simply carried on the bristly legs of the fly and be deposited later on human food, or they may actually pass through the fly's alimentary canal. (The housefly plays a part in carrying other diseases besides

typhoid from place to place and inoculating human food.) Another source of typhoid in England has been through the consumption of uncooked or poorly cooked shellfish (mussels in particular) collected from the sea shore near a sewage outfall. Of course, mussels should not be distributed from such beds at all, but as they often grow large in such neighbourhoods they are frequently taken and sold by individuals with either no knowledge of the danger or no thought or care for the consequences to human life so long as they are not caught.

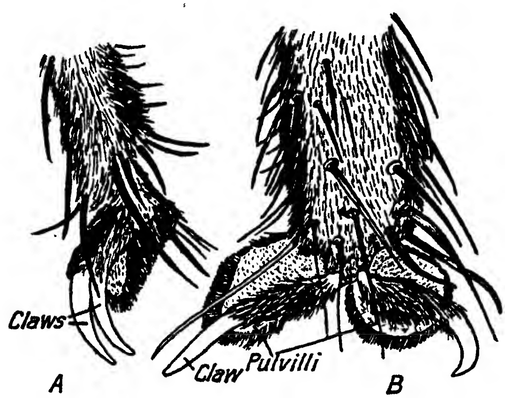


FIG. 233.—Legs of housefly.
A. Side view. *B*. Dorsal view. (After Röseler and Lamprecht.)

One of the most interesting and important reactions of an animal which is invaded by parasitic bacteria is the production of substances which tend to destroy the bacteria, or to neutralise their poisons or both. Thus, it is well known that an individual who has had measles, scarlet fever or smallpox is not likely to be reinfected. In other examples the susceptibility of the host to the toxins of the parasites becomes lessened. Besides this acquired property, however, all animals are not equally susceptible to bacteria. This feature is known as **Immunity**, and we may recognise **Natural Immunity** and **Acquired Immunity**. Thus, in any community tubercle bacilli fail to obtain any hold on many individuals throughout life, whilst others succumb to consumption at an early stage. There may, of **Immunity**

course, be conditions of environment which increase the danger (underfed people working in badly ventilated factories will be more liable than farmers in the dry regions of Australia or California), but apart from this, and taking only individuals working at the same trade and brought up in the same way, there is a well recognised inherited susceptibility which is at the back of most serious cases of consumption. Again, some species of animals are by nature immune to bacteria which will live well in other species. Evidently the chemical constitution of the body of these naturally immune individuals is unfavourable to the growth of the bacteria concerned.

In cases of acquired immunity, we assume that the body of the host is so stimulated by the parasites that it produces substances (antibodies) which neutralise their poisons or even help in their destruction. The antibodies are produced in surplus quantity, so that after the invading bacteria are conquered and the disease comes to an end there is a surplus left which prevents another attack. This alteration in the body may last for many years. Unfortunately not all bacteria cause the host to respond in this manner. A common cold or influenza may not prevent another attack even a few weeks later.

One of the most valuable discoveries of medical science is that we can produce a particular immunity in some cases without the individual having to suffer a serious invasion by the bacteria concerned. Various methods are used, involving the injection of dead bacteria, living bacteria whose virulence has been attenuated, or of fluids from an immunised animal containing the substances which antagonise the bacteria or their products.

One of the most successful applications of this discovery, which saved thousands of lives during the Great War, was the production of immunity to typhoid fever by the injection of two doses of typhoid bacteria cultures which have been killed by heat. Vaccination against smallpox is another application of the same kind. In cases of diphtheria many lives are now saved by injecting into the patient antibodies which neutralise the poison which the diphtheria

bacterium produces. These antibodies are obtained on a large scale by injecting doses of living diphtheria bacteria into a horse. The first dose is chosen of such a strength that it does not harm the animal, which reacts and produces the antibodies in its blood. One can then successively increase the doses until the blood contains a relatively large amount of diphtheria antibodies. A quantity of the blood can be run off without injuring the horse, and from this the serum containing the precious substance is obtained. Substances so produced are called **Antitoxins.** An antitoxin for the lockjaw bacterium can be obtained in the same way. Thus a use has been found for this remarkable reaction of the animal body to invasion by foreign organisms.

XXI

THE ANIMAL AS A WHOLE. EVOLUTION, HEREDITY, ETC.

IN the previous chapters of this book we have considered the functions performed by the various parts of the animal body, the activities which are fundamental to and characteristic of a live animal. It is true that we have emphasised the necessity of studying living animals in a chapter on pond life, and we have studied a few of the simplest animals (Amoeba and Paramecium) as a whole. Notwithstanding the fact that we have repeatedly emphasised the harmony and control exerted by one part of the body on another, we may have laid the student open to a grave danger—the assumption that an animal is merely a collection of organs or a collection of cells, and that all its activities can be explained by physics and chemistry. This could not be helped. The animal utilises and depends upon chemical phenomena, and there is no better method of studying the striking manifestations of life than that of taking one function and viewing it as it is performed in different animals. Another method would have been to take a number of animal types separately, but this usually leads to a greater danger, for the student fails to see the underlying resemblances, and by the time he has finished his course he knows something about the frog and a crayfish and a worm, but little about the fundamental features of animal life. We must, however, provide some kind of an antidote to the danger of our method of treatment.

The processes of digestion, excretion, respiration and the action of sense organs depend upon the phenomena of physics and chemistry. Possibly all the phenomena of life might be explained if we knew more about the complex physics and chemistry of the living organism. Some scientists think so. Others regard the wonderful and harmonious regulation which exists in the living organism as

indicating something more than physics and chemistry, and at present there is much debate about the matter. It is far too difficult a subject for an elementary book on biology, and our purpose will be served if we warn the student. When we come to such matters as instinct and intelligence, it is more difficult still to think of a physical or chemical explanation, and it is extremely difficult to study these phenomena even in man. It is thus almost impossible to interpret the actions of bees and ants in terms of human life, although such an interpretation is often attempted, and we hear the 'busy bees' or the ant extolled as examples to the lazy man.

Evolution

In the animal world we are presented with a huge collection of varied creatures, with diverse habits and exhibiting countless adaptations to an infinitude of environments. The bottom of the ocean, where there is no light and the pressure may be five tons to the square inch, is not without life. Living animals are found high up on Mount Everest, in hot springs, and in desert places. Probably over 650,000 different kinds or species of animals have been described and named to date, and every day collections containing new species are being received by experts. Have all these different types existed for ages on the earth, each adapted to its little niche, or must we look for some other explanation of the existing animal world to-day?

Everyone must know that our numerous varieties of dogs are largely the result of the ingenuity of breeders. The collie, the greyhound, the dachshund, the toy dogs of all kinds have been produced by breeding, and there is as much difference between some of these dogs as between many different wild species. Take the horse, for example, and we see the same thing. Man has produced horses as unlike as the great heavy draught horses (Clydesdales) and the speedy race horses.

It is true that there is something common to all dogs, and no one would mistake a draught horse or a race horse for anything but a horse if previously only one or the other had been examined. But we have already seen that there is much that is common to all vertebrates. The skeleton of the fore limbs of the bird, crocodile, whale, horse and man

is fundamentally the same, although the uses of the limbs and their shape may be different. And thus, just as we recognise the present-day dogs as having arisen from some one ancestor in the past and in a comparatively short time, so it is generally accepted now that the animal kingdom as we see it to-day has come into being by a process of gradual change through the ages, by evolution, in other words by descent.

We have written the previous pages of this book on the assumption that the 'higher' groups of vertebrates have arisen from ancestors belonging to the 'lower' groups of ancient times. If we carry this conception to its logical conclusion, then we must regard the group of the simple single-celled animals—the protozoa—as having provided the ancestors of the metazoa, and so on. This great conception of evolution is a key to the understanding of much in animal and plant life, and it is supported by a substantial amount of evidence, the trend of which we shall briefly indicate. Before doing so, however, it is necessary to warn the reader that Evolution and Darwin's Theory *are not the same thing*. Theories of Evolution date back long before Darwin, and the evidences of evolution are well founded facts. Charles Darwin's great work was not only to marshal the facts, but to put forward an extremely thoughtful and strongly supported theory to explain *how* evolution of animal life had taken place and what forces had controlled it. We are omitting the whole of Darwin's Theory from this book and also all other theories of Evolution. To do justice to them would require more space than can be spared, especially since it would be true to say that although we know far more to-day of Heredity and Variation than was known in Darwin's time—very much is still to be learned, and whilst Evolution is now an accepted belief the methods by which it took place are still a matter of considerable debate.

However, we *do* want to stress the fact (newspapers constantly fall into error over this) that evolution and Darwinism are two different things, and a belief in one does not necessarily mean a belief in the other.

Intimately connected with the study of evolution is the study of heredity, because obviously if we regard the animals

of to-day as having arisen by slow and orderly change from animals of the remote past, we must be particularly interested in the relations of the resemblances and the differences—between parents and offspring. Under the term Heredity, we include the relationship between successive generations. A little study is sufficient to show that there is some mechanism which tends to make the offspring like the parents. The egg of an animal gives rise to its own kind. Often we can go further and see most remarkable resemblances even to the inheritance of the mental characters in man. This is exemplified by several old adages, such as 'like begets like.' If there were always an absolute resemblance between offspring and parents, no evolution could ever have taken place, and we could never have bred our domestic animals. 'Like begets like' is really incorrect, and should be written 'like tends to beget like.' Thus of twin boys, both of whom have had identically the same upbringing, one may be fond of books and top of his form at school, but not physically strong; the other may be very proficient at games and not particularly bright at bookwork. And in any family of animals there will be differences of one kind or another. These degrees of difference are known as **Variations**,[1] and it is upon them that the possibility of evolution rests. We study heredity, however, for other reasons than its interesting relationship to evolution. The production of our domestic breeds of cattle, horses, poultry, wheat, fruits and so on is one result of observations on heredity. Our knowledge regarding certain diseases in man (*e.g.* tuberculosis) involves a close study of heredity.

Evidences of evolution

Now let us marshal together some of the evidence which leads us to accept evolution as a fact. If a change has taken place resulting in the gradual evolution of the animal world as we know it to-day, then if it were possible to have some of the remains of animals which lived long ago, they should present some indications of this evolutionary change. Fortunately we have found such remains, and it is surprising how much they have told us. It is surprising, because under

[1] The term Variation is used in very different senses (see page 452).

ordinary circumstances the dead body of an animal soon decays, even if it be not eaten by some other animal, smashed to fragments on the sea shore or otherwise destroyed. Yet not only have isolated individuals been preserved in the remote past, but they have existed through millions of years in some cases and then (and this is just as necessary) been found by man to-day. The specimens are known as **Fossils.** Generally only hard parts—skeletons—have withstood decay and obliteration through the ages, but in a few cases indications of softer tissues are preserved. The most wonderfully preserved fossils are the insects which were trapped and enclosed in the gum exuding from trees. In this way the most minute details of external structure have been effectively preserved. After many thousands of years the gum became amber. Another example is the mammoth which was found frozen in the ice in Siberia. These examples, however, are not of the greatest age. Perhaps the most general means of preservation is the covering of animal remains by deposits of fine mud or sand, which eventually become converted into rock. Geologists describe rocks rich in animal remains as highly 'fossiliferous.' When such rocks are metamorphosed (*i.e.* changed by heat, pressure, etc.) all traces of animal remains tend to be destroyed, so that an originally fossil bearing sandstone may be represented to-day by a quartzite quite devoid of organic remains.

Igneous rocks which have welled up from underneath the surface of the earth (granites, diorites, etc.) cannot contain animal remains, and surface life caught in basalt flows is destroyed by the great heat. People often talk about Herculaneum and Pompeii having been preserved by lava, but in reality one was buried in dust and parts of the other in mud (rain and dust).

It will be realised then how remote have been the chances of fossilisation and what a mere remnant of past life could have been preserved (even if all possibly obtainable fossils were already discovered).[1] This explains why fossils have

[1] In this connection too it might be noted that four-fifths of the earth's surface are under water.

not solved more of the problems of evolution. They do show, however, that the animal life of past ages was very different from that of to-day. They show that the higher vertebrates did not exist at the time when the earliest fossil-bearing rocks were being formed at the surface, and they show that fishes existed before reptiles and reptiles before birds and mammals. Some fossils give us quite a picture of evolution. The most famous example of all is the evolution of the horse (Fig. 234). We see here quite clearly the stages by which the feet gradu-

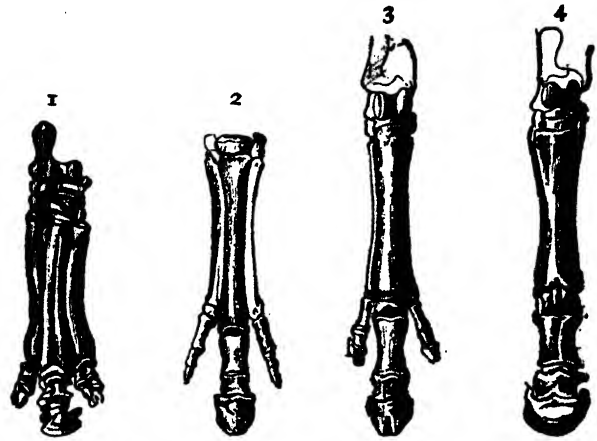


FIG. 234.—The evolution of the foot of the horse. (From Borradaile.)
1. Palaeotherium (Eocene period). 3. Hippotherium.
2. Anchitherium. 4. the modern horse.
Note continuous reduction of toes.

ally changed until the modern horse with only one toe to each foot was derived from its four or five-toed ancestor.

Next we have the evidence of evolution from **Comparative Anatomy.** We have pointed out several times that the vertebrates have practically the same fundamental structure, notwithstanding the differences in external form and the habits of life. For example, the same parts can be traced in the wing of the bird, the flipper of a dolphin and the arm of a man. The theory of evolution provides the only satisfactory explanation of this and related phenomena. This same theory also explains the occurrence of organs, which are present in some animals in a reduced condition and are apparently functionless (traces of limbs in the snakes —Fig. 235) relics of an ancestral condition.

The study of **Embryology**—the development of an animal from the egg—lends considerable support to the theory of evolution. Frequently we have seen that an animal passes through different stages and forms before the adult stage is reached, and sometimes these developmental stages resemble the adult form of other animals existing to-day. Thus the frog passes through a tadpole stage, which is very fish-like, and actually in the development of the chick and the rabbit there is a stage when traces of gill slits are found.

The **Geographical Distribution** of animal life on the earth to-day can only be satisfactorily explained by means of the Theory of Evolution. Each part of the world has its characteristic fauna notwithstanding that the environments may be alike. The characteristic animal life of South America is quite different from that of Africa, but the fauna of Australia is the most striking of all in this respect. Egg-laying mammals like the duck-billed Platypus and the Echidna are found nowhere in the world but Australia and New Guinea. Moreover, the Australian and New Zealand animal life is just as peculiar in types which are absent as in types which are present. Until man imported the cattle and sheep there were no Ungulates whatever, and no carnivorous animals except the dingo, which was probably brought in by the natives. The fauna of these countries can be explained if we assume that Australia was separated as an island from the other land masses at an early date, before the evolution of the higher animal groups which are common elsewhere, but are absent from this part of the world.

Heredity

Now let us glance at some of the results of the study of inheritance and of their application to human affairs.

There are two methods of reproduction—asexual and sexual. In sexual reproduction generally two parents are concerned. In asexual reproduction, whether it be by the division of an animal into two, as in *Amoeba* or *Paramecium*, or by the production of buds, as in *Hydra*, the new individual consists of the same material as the parent, and it would not be surprising to find no difference between one generation and another. On the other hand, when a new individual arises from a fertilised egg, as in the

majority of cases of sexual reproduction, the offspring evidently receives something from both parents, and if the parents are different we should expect to find the offspring somewhat different from one or from both.

Experiments appear to show that the spermatozoon is equivalent to the egg in respect to the handing on of whatever is inherited, although it may be far inferior in size. At the present time the mechanism responsible for the development of the characters of a parent in the offspring is supposed to lie in the chromosomes of the nuclei (see page 341) of the reproductive cells. The whole problem is, however, complicated seriously by the most important fact that the characters of any animal developing from a

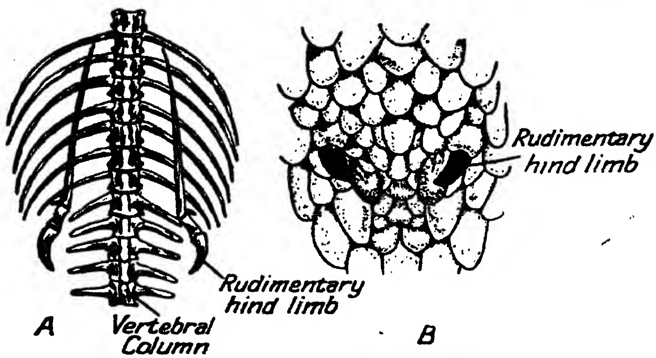


FIG. 235.—Hind limbs of a python.
A. Skeleton. *B*. As seen on ventral surface. (After Romanes.)

fertilised egg depend not only upon the factors contained in the fertilised egg, but upon the action of the environment. Thus in all studies of heredity we must remember that the assemblage of characters of any adult animal is due to the combined effect of inheritance and environment. During the years after the war, the maimed rickety children of Vienna were not so because of any defects inherited from their parents, but because they had had improper and insufficient food.

The greater weight and better physique of the average one-year-old Australian babies as compared with the average for English babies of the same age is possibly affected a little by inheritance, but is most probably almost entirely due to better environment in the complete sense of the word.

It is not always easy to distinguish between what is caused by environment and what is primarily due to inherited factors (see Variations, page 452), but there are certain plain cases which indicate law and order in inheritance, and as these may be experimentally tested by the simplest means, we shall describe some of them here. The laws were discovered by an Austrian monk named Mendel about the years 1860-1865, and the type of inheritance studied by him is often known nowadays as Mendelian Heredity.

Mendelian inheritance

Our edible pea plant is represented by several varieties. There are tall and dwarf forms, plants with yellow seeds and plants with green, some with ripe seeds which are round, whilst others have seeds which are wrinkled, and so on. Take a tall variety, and it will be found that its seeds give rise to tall plants. Try the same with a dwarf variety, and it will be found that the offspring are dwarf. In the edible pea the flowers contain both pollen and ovules, and normally the flowers are self-fertilised, that is, the pollen of one flower fertilises the ovules of that same flower. There is, therefore, normally no breeding between two different parents. This is an important feature, which renders the edible pea peculiarly suitable for experiments. Now suppose we take some young flowers growing on a tall plant before the pollen has been set free and we cut off the male organs which bear it (stamens). Then cover up the flowers with a waxed paper bag to shelter them from insects and wind, which might bring pollen from other pea plants. Next, take a little pollen from the flowers of a dwarf plant and dust it on the stigmas (the female part for the reception of pollen) of the flowers operated on, and again cover them up. In this way the ovules of the tall plants will be fertilised by pollen from the dwarf plants, and the whole may be compared (although it is not quite accurate to do so) to spermatozoa from a male animal fertilising the eggs of a female. The fertilised ovules become seeds in due course. Sow the seeds of these treated flowers and await events. They should all give rise to tall plants like one of their parents (in this case the female). Mendel was the first to show that this was not the end of the story, and that these tall plants

were not quite what they seemed. They have arisen from parents which differed between themselves in one quality—that of stature. They are therefore **Hybrids**, although they appear to have inherited the stature character of only one, the tall, parent. Now, if the flowers of these tall hybrids are allowed to grow in the normal way and fertilise themselves, and if the seeds are carefully collected and sown, it will be found that the resulting plants are of three different types *and they occur in a definite numerical proportion.* Twenty-five per cent. will be dwarfs (although their parents showed no outward signs of dwarfness) and seventy-five per cent. will be tall plants. We have seen, however, that it is possible to have two kinds of tall plants, and that it is only possible to detect the differences by breeding. Test out then the seventy-five per cent., and it will be found that one-third of them are 'pure,' tall like the original parent of the experiment, that is, they only give tall offspring, whilst two-thirds act like the tall hybrids. The character which appears in the first hybrid generation (tallness) is termed the 'dominant,' and the one it masks is termed the 'recessive' (dwarfness). We can now represent the results of the experiments by a simple diagram.

Tall pea plants (these plants self-fertilised give nothing but tall offspring)	crossed with	Dwarf pea plants (these plants self-fertilised give nothing but dwarf offspring)

give
↓
all tall plants (hybrids).
↓
These tall hybrid plants
self-fertilised give

25% Tall	50% Tall	25% Dwarf
(which when tested produce nothing but tall plants, *i.e.* they are pure).	(which when tested appear to be hybrid like their parents).	(which when tested produce nothing but dwarf plants, *i.e.* they are pure).

This experiment can be repeated with animals using pairs of characters which act towards each other in the same way.[1]

A few examples illustrating some of the problems elucidated by the application of Mendelian analysis are given in an appendix.

We cannot go any further into the subject of Mendelian inheritance here, although we have only touched the fringe of what is already known about Mendelism. The example must not be taken as anything more than a very simple and isolated case. Characters do not always behave to each other as dominants and recessives, and many things may happen in breeding which are not suggested in the example. It has been given for two purposes only. The first is to show how an experiment in inheritance may be carried out, and to show that in the production of offspring from a cross there is some definite mechanism at work—something controlled by laws. The second purpose is to show that a character may appear to be lost, and yet may only be undeveloped. The result is that it may reappear in a later generation, and consequently we may find the offspring very unlike their parents, just as the hybrid tall peas give 25% dwarfs.

The advanced student may like to know what is regarded as the mechanism responsible for our simple Mendelian experiment. He will remember that each plant and animal has a characteristic number of chromosomes in its cells, and that this number is halved when ripe eggs and spermatozoa are produced. Since the full number is restored when an egg is fertilised by a male cell, it is clear that half the chromosomes in any cell have descended from those brought in by the spermatozoon at fertilisation and half have descended from those present in the egg. We could assume, then, that every character is represented by two factors, one on one chromosome and one on another. Let us apply this to our pea example. The seed of a normally self-pollinated *tall* pea would have two factors for tallness, because it received one

[1] A similar result to that of this experiment would be obtained if the pollen were taken from the tall plant and used to fertilise flowers on a dwarf.

in the batch of chromosomes in the ovule and another in the batch of chromosomes in the pollen grain. Similarly the seed of a normally fertilised *dwarf* pea would have two factors for dwarfness. But the seeds resulting from the cross pollination would have one factor for tallness (received from the mother plant by way of the ovule) and one factor for dwarfness (received by way of the pollen grain from the dwarf pea). We have seen that this seed with the two different factors gives rise to a tall plant. We assume therefore that one factor dominates the other, but we also assume that both remain unchanged. Now when this tall plant produces ovules and pollen grains and the chromosome contents are halved, an ovule or a pollen grain only gets one chromosome containing the factor for stature. It must have either a tall or a dwarf factor, but cannot have both. Thus the hybrid tall pea plant produces really two kinds of ovules and two kinds of pollen grains. The rest is easy. If a pollen grain with a factor for tallness fertilises an ovule with a similar factor, you will have a seed with two factors for tallness and a pure tall plant will result. If a pollen grain with a factor for dwarfness meets an ovule with a factor for dwarfness, you will have a seed with two factors for dwarfness and a pure dwarf will result. If the pollen grain and ovule which meet have different factors, a hybrid will result, and it will always be tall because we have seen that tallness dominates dwarfness. Now if the two sorts of pollen grains and ovules be produced in equal numbers, and if their meeting is a pure matter of chance, then the result will be the same as our breeding experiment, for the chances are that 25% of the pollen grains with tall factor will meet an ovule with the same factor, 25% of the pollen grains with the dwarf factor will meet an ovule with the same factor and 50% of the meetings will be of ovules and pollen grains bearing different factors.

In these examples there is no mystery about the reappearance of these characters. But how did the characters arise in the first place? How did there come to be tall and dwarf types, yellow-seeded and green-seeded types, brown-eyed and blue-eyed human beings, and so on? It is the *origin* of variations that is so important from the point of view of evolution. They are familiar everywhere,

and they affect every sort of character. They are at present the object of much study and great argument.

Variations We have seen that variations are the differences between individuals of the same species, that is, differences between closely related individuals. It has also been pointed out that two adult organisms may differ, because their constitution has been different from the very beginning, *e.g.* the twins referred to on page 443, or because the animals have been subjected to very different environments (such as the difference between an individual brought up as a clerk in a smoky town and one brought up as a blacksmith in the country).

The differences between individuals which are produced by the unequal influence of different environments are often called **Modifications**, and it is a matter of great dispute whether they are inherited or not. On the whole, the evidence at present seems to show that they are not inherited, for nothing new is produced in such cases, only the repression or the favourable development of some potentiality already present. However, it would still be well to keep an open mind. Even if we believe that these modifications (the muscles of the blacksmith, the dyspepsia of the business man, the difference in size of plants grown in alpine regions compared with the same species brought to the plains) are not inherited, this does not mean that the action of the environment is not a big factor in the production of variations. Variations between individuals produced as the offspring of two parents will arise through all sorts of combinations and recombinations of hereditary units. Variations may be due to some inherent character of the germ plasm which causes it to vary in composition. Variations probably arise also through the action of the environment (in the widest sense of the word) on the germ plasm. Hereditable differences may be produced in this way.

Thus the environment may act by (1) allowing or repressing the development of characters which have been inherited (and thus determining the degree of their development); (2) producing new characters through acting on the germ cells or more correctly on the germ plasm.

It is easy to understand how difficult it has been to appreciate the manner and degree of action of the environment. The fact is, we do not yet know how the internal rearrangements causing the variations which have resulted in evolution have been brought about, and thus we are not quite sure yet whether the environment has had any *directive* influence in *initiating* variations in special directions.

Biology and human life

Anyone who has studied the previous pages and carried out the practical work will have already noticed many facts which bear upon human welfare. The great advantage of biology as a science in a general scheme of education is that it deals with something that is important to us all, for man, in so far as the functions of his organs are concerned, is as much an animal as any we have studied. We ought therefore to appreciate the essential features of respiration, nutrition, the circulation, excretion, the nervous system and reproduction in man after we have experimentally studied these functions in the lower animals, and especially in the rabbit.

There is, however, one very important difference between human life and that of all the other animals. Man has been given the power of choice, and he is guided or should be guided by his intellect, whereas in other animals the functions and activities are generally controlled by instinct. This means, of course, that man is exposed to more danger, and must be educated to some extent to overcome it. The more our environment becomes an artificial one and the more we have the power to develop and control our surroundings as we have in modern civilisations, the more necessary does this education become. A sheep is adapted entirely to a subsistence on grass, and its instincts cause it to eat grass. It is true that its instincts will not always lead it to choose grass in a suitable condition, nor can it avoid grass infected by certain parasites. We, however have the choice of an unlimited number of substances, some of which serve no useful purpose and others of which are dangerous. We can prepare our foods for our use, and we can also spoil them. The exercise of our will and of our

power of choice becomes then often a disadvantage, even a danger, instead of a help. We tin good food, and frequently add to it deleterious chemical 'preservatives' without any knowledge of their likely effect on the body. It becomes almost a necessity in these days of potted shrimps preserved with boracic acid to know something about foods and food values. In Chapter IV. we saw that fats, carbohydrates and proteins were the essential animal foodstuffs, together with certain salts and the newly discovered vitamins. Now it is possible to purchase very different quantities of these substances for the same sum of money, for some bought foods are more expensive than others, and the actual percentages of fats, proteins, carbohydrates, etc., vary very greatly. In other words, instead of paying for the actual amount of nutriment present in the food we buy, we pay for flavours, for something that the individual likes, or for caprice. Too often, however, we pay for our ignorance. This is all illustrated in the table on page 455, which shows in the right-hand column the relative cost of purchasing a definite calorific value and the most extravagant, as also the most economical way of purchasing food.

Of course, one cannot always use the cheapest method of obtaining a sufficiency of fats, carbohydrates and proteins. Food cranks too often suggest that everybody should eat this or that because it contains the essentials, and is perhaps in most cases a good food. They reckon without the human element, and it often happens that 'one man's meat is another man's poison.' Thus such a table as is given below should be used with discretion.

Much has recently been advertised regarding the need for more vitamins. Probably sufficient are present in natural foods in a good properly balanced diet. Unfortunately they are often destroyed by cooking or preserving.

The prices of foodstuffs constantly vary and have changed considerably since the first edition of this book. The correct figures for the last three columns of the table on page 455 can, however, be calculated easily by comparing current food prices with those in the column headed 'Average Price per lb.'

More knowledge of the bacteria and of their distribution would lead naturally to greater cleanliness in the preparation of foods. It is important to remember that it is not always the actual amount of dirt, dust and other contamina-

tion that is dangerous, but that the contamination, if bacterial, is a live one and increases rapidly, since the food-stuffs often provide a very suitable growing medium. The

COMPOSITION OF ORDINARY FOOD MATERIAL

Food values

Kind of Food Material.	Edible Portion.						Average Price per lb.		Fuel Value per lb.	Cost of 500 calories.	
	Water.	Unavailable Nutrients.	Available Nutrients.								
			Protein.	Fat.	Carbo-hydrates.	Ash.					
	%	%	%	%	%	%	S.	D.	Calories	S.	D.
Beef (fresh):											
Brisket	54·6	2·1	15·3	27·1	...	0·7	1	0	1475	0	4
Sirloin	60·6	1·8	17·9	19·2	...	0·8	2	0	1185	0	10
Round	65·5	1·6	19·7	12·9	...	0·8	1	9	950	0	11
Rump	56·7	2·0	16·9	24·2	...	0·7	2	6	1380	0	11
Suet	13·7	4·3	4·6	77·7	...	0·2	1	4	3440	0	2½
Beef (preserved):											
Corned	49·9	2·7	14·2	31·4	...	2·2	0	10	1635	0	3
Lamb (fresh):											
Leg	63·9	1·7	18·6	15·7	...	0·8	1	8	1050	0	9½
Shoulder	51·8	2·2	17·6	28·2	...	0·8	1	6	1565	0	5½
Mutton (fresh):											
Leg	62·8	1·7	17·9	17·1	...	0·8	1	8	1095	0	9
Neck	58·1	2·0	16·4	23·4	...	0·7	1	6	1335	0	6½
Bacon	18·8	4·8	9·6	64·0	...	3·3	1	10	2950	0	3½
Ham	40·3	3·6	15·8	36·9	...	3·6	2	0	1095	0	6½
Pork Sausage	39·8	3·1	12·6	42·0	1·1	1·7	1	6	2080	0	4½
Turkey	55·5	1·9	20·5	21·8	...	0·8	1	10	853	1	1
Cod Steaks	79·7	0·9	18·1	0·5	...	0·9	1	1	385	1	5
Lobster (canned)	77·8	1·3	17·6	1·0	0·4	1·9	4	3	400	5	3½
Eggs (uncooked)	73·7	1·1	13·0	10·0	...	0·8	1	8[1]	695	1	2½
Whole Milk	87·0	0·5	3·2	3·8	5·0	0·5	0	3	310	0	5
Condensed Milk (sweetened)	26·9	1·2	8·5	7·9	54·1	1·4	0	8½	1460	0	3
Cream	74·0	1·1	2·4	17·6	4·5	0·4	3	0	860	1	9
Cheese	34·2	3·4	25·1	32·0	2·4	2·9	1	8	1885	0	5½
Butter	11·0	4·9	1·0	80·8	...	2·3	2	1	3410	0	3½
Margarine	9·5	5·7	1·2	78·9	...	4·7	0	10	3335	0	1½
Oatmeal and Rolled Oats	7·8	5·6	13·4	6·6	65·2	1·4	0	3	1795	0	1
Rice	12·3	3·7	6·5	0·3	76·9	0·3	0	3	1610	0	1
Spaghetti	10·6	4·0	9·4	0·4	75·1	0·5	0	5	1640	0	1½
Brown Bread	43·6	2·8	4·2	1·6	46·2	1·6	0	3	1035	0	1½
White Bread	35·3	3·3	7·1	1·2	52·3	0·8	0	2½	1195	0	1
Sugar:											
Granulated	...	...	...	...	100·0	...	0	3½	1790	0	1
Brown	...	...	...	...	95·0	...	0	3	1700	0	1
Carrots	88·2	1·0	0·7	0·4	8·9	0·8	0	1½	200	0	3½
Peas (dried)	9·5	7·6	17·3	0·9	62·5	2·2	0	3½	1508	0	1
Potatoes	78·3	1·4	1·7	0·1	17·7	0·8	0	1	370	0	1½
Tomatoes	94·3	0·4	0·7	0·4	3·8	0·4	0	6	100	2	6
Beans, Baked (canned)	68·9	2·7	4·8	2·3	19·7	1·6	0	5½	555	0	5
Apples	84·6	1·6	0·3	0·5	12·8	0·2	0	5	260	0	9½
Bananas	75·3	2·7	1·0	0·5	19·9	0·6	0	4½	400	0	5½
Strawberries	90·4	1·0	0·8	0·5	6·8	0·5	0	9	160	2	4
Raisins (dried)	14·6	9·1	2·0	3·0	68·7	2·6	1	0	1410	0	4½
Prunes (dried)	22·3	8·3	1·6	...	66·1	1·7	0	9	1230	0	3½
Almonds	4·8	10·9	17·8	49·4	15·6	1·5	0	10	2685	0	2
Peanuts	9·2	10·7	21·9	34·7	22·0	1·5	0	4½	2255	0	1

[1] At 2s. 6d. per dozen.

individual with no conception of biology might not think it mattered if two flies washed their little legs in a quart of milk intended for the baby. A little knowledge, however,

would make it clear that it was not going to be a question of the amount of dirt introduced into the milk, but of the degree this contamination would have reached at the end of a warm summer's day.

What has been said above about the subordinate effect of instinct to man's ingenuity and intelligence in regard to nutrition applies to the other functions too. We frequently live under highly abnormal conditions in regard to the function of respiration. We have converted the air of our towns into a mixture which is often almost poisonous. We have (in the past certainly) often hindered the proper action of part of our respiratory organs by our clothing. Our nervous systems are strained to a surprising degree by the life in our cities. Our excretory organs are probably affected by our food and drink—apart from the extreme cases where it becomes obvious. Our teeth seem liable to decay, whatever we do, and intestinal troubles are advertised daily. Nerve trouble, neurasthenia and insanity are certainly more common than in the days of our Norman and Saxon ancestors. Every function can be upset, can be abused, and this applies to that of reproduction, a perfectly normal and beautiful function, which must be exercised in a normal manner.

It is not our intention to discuss all these features here. The student who has taken a course in biology will realise the harmony which exists between the different parts of the body. He should be able to realise, then, without further instruction that all the organs must be kept working in as natural a manner as possible.

The human body was not evolved in an environment of coal mines, factories, shipping offices, or exciting literature and preserved food. And if we have found it possible to live under such conditions, it is well to remember that most of us have outrun our adaptation to them. Keeping this in view we shall not only seek remedial doses of 'back to nature,' but we shall devote a little more effort to making our towns fit to live in.

XXII

SOME GENERAL INSTRUCTIONS FOR LABORATORY WORK

It is essential that animal biology be studied as a practical subject involving experiment, observation and simple dissection of suitable examples easily procured and handled frequently in everyday life.

With a view to reducing the size of this book as far as possible, much of the usual lengthy descriptions of animal structure has been left out. Practical experience leads the author to think that a series of illustrations are of as much service as detailed description. The following pages should be used, therefore, in conjunction with the different sections of the book (see Index). They are brought together here merely for convenience, and it is not intended that this section should be read or studied as a unit by itself. It is really a reference appendix.

PRELIMINARY NOTE

It is essential that habits, movements, etc., should be studied on living animals and, so far as possible, under natural conditions as indicated elsewhere in this book. Where dissections are to be made or small animals are to be mounted and stained for microscopic examination, it is necessary to kill the animal. Now it must be realised at the outset that the student of animal biology should be one of the last persons to be guilty of cruelty to animals. Whatever the animal, whether it be a rabbit or snail or microscopic Amoeba, it should be killed so painlessly (slowly with narcotisation, or suddenly as the case may require) that the animal dies extended with all the parts in

undistorted condition and with as close an approach to the natural form as possible. The tissues must also be killed and fixed (fixing reagents are given below), so that they will withstand later treatment. Care must be taken, therefore, that proper killing methods are always used and, except in special cases, observations are not made on animals which are picked up dead or in a diseased or injured condition. Methods are given below or elsewhere in the text.

Dissection should be carried out where possible under water. This, of course, cannot be done for large animals like the dogfish or rabbit. Enamel pie dishes make excellent dissecting dishes, and they should be lined with a layer of paraffin wax on the bottom, so as to provide a base on which to pin the animal. The larger animals should be dissected on suitably sized boards which can be taken away and washed.

MICROSCOPIC PREPARATIONS

Tissues and small objects may be examined in the form of temporary preparations, dry or immersed in the fluid which usually bathes them, or in a suitable artificial one such as 0·75% solution of common salt for the tissues of frog and 0·85% for mammal. For more permanent preparations, the objects may be mounted dry, if suitable, or in glycerine jelly, or in canada balsam. The first method is of limited use, and only applies to structures like scales of butterfly or scaly skin of a fish. Preparation is only a matter of applying a thin cover glass and cementing this down to the glass slide. Gold size is generally used for this purpose and applied in small quantity with a brush to the edges of the cover glass.

The **Glycerine-jelly** method is a quick one, but not so permanent as canada balsam. It is on the whole best to purchase the glycerine jelly from a reliable firm of makers of microscope accessories, etc. The glycerine jelly is melted by standing the bottle in warm water. The object, which may have been dry or in water, is placed on the slide,

covered with a drop of melted jelly, and the cover glass is carefully placed on so that no air bubbles are included. It is often better to take the object from water and leave in ordinary glycerine just before mounting in the glycerine jelly. The jelly soon becomes firm. It is advisable to supply a little gold size round the edges of the cover glass after a few days.

Canada Balsam. Objects and tissues to be mounted in canada balsam must have all the water withdrawn from them first. This is done by abstracting the water with absolute alcohol. In order to prevent distortion, it is usual to bring a tissue which is in water gradually to absolute alcohol by passing it through baths of 30% alcohol, 50%, 75% and 95%, and then one or two applications of absolute alcohol. After thorough removal of the water the preparations go into xylol, benzol or clove oil. The reason for this is, that canada balsam will not mix with absolute alcohol, and so an intermediate substance is used to make the passage possible. After soaking in benzol (in which the tissue will become clear if properly treated beforehand) or clove oil, a drop of canada balsam is placed on a slide, the object brought quickly into it, arranged in position with a fine needle, and a cover glass carefully lowered upon it. The slide is then put away in a horizontal position for a few days until the canada balsam is hard. If the tissue has not been dehydrated properly a milkiness with opacity will be noticed at the benzol-xylol stage or the canada balsam stage. The only remedy is to go back to absolute alcohol.

THE STUDY OF TISSUES AND CELLS

The study of the structure of animal tissues is too often restricted to sections made and stained by complicated methods. It must not be forgotten that much can be made out from temporary preparations and by simple methods of teasing or tearing apart the cells with a pair of needles, and that in any case this is a very necessary complementary method to the more complicated ones.

(*a*) *Teased Preparations.*

Teasing is useful for study of muscle and nerve fibres. A small piece of *muscle* from the leg of the frog is placed in a drop of salt solution on a glass slide, and with a fine pair of needles the individual fibres are separated. One should try to separate the fibres and not to break them across. The tissue can be examined without staining after covering with the cover glass.

Nerve can be examined in the same way. Sometimes it is convenient to stain teased preparations by the methods given below. In such cases, if fresh tissue has been teased, it is advisable to add a drop of alcohol (absolute) on the slide and allow it to act upon the tissue before staining.

(*b*) *Maceration Preparations.*

It is often useful to employ chemical means to separate the cells or other parts of a tissue. Slight tapping on a cover glass, or touching, will then often isolate the different cells or other structures. This method should be used to obtain *nerve cells* from the brain or spinal cord. A small piece of spinal cord is left in 0·1% solution of Potassium bichromate for two days or longer. It may then be placed in water or glycerine under a cover slip and the parts gently separated by tapping. It is preferable to stain the tissue after maceration, but before separating into parts, by placing the piece of tissue, after washing out the Potassium bichromate, in a watch glass of Picrocarmine (see below), for some minutes.

STAINING METHODS

For staining isolated cells obtained from teased preparations, for macerations and for insect and other larvae, etc., the following methods are useful. It should be noted that very few dyes stain living cells, and when this is possible only certain parts of the cell are stained. In the case of maceration preparations and most teased preparations the cells will, of course, be dead. It may be required, however, to stain parts of living cells—*Amoeba* and *Paramecium*—

and also living insect larvae and small transparent Crustacea like *Daphnia*. This is possible without injury, and the results are often very valuable.

Vital Stains for Living Cells and Small Transparent Organisms.

Neutral Red is one of the best of these for Protozoa and fresh-water life, including Rotifiers, Copepoda and Daphnids. The secret of success lies in using a very weak solution of the stain and allowing it to act for 2-6 hours. Unfortunately, it is almost necessary to find out the suitable concentration for each case. For Daphnids the solution in the water in which they are living should be merely 'pink' in colour (1 in 2,000–1 in 10,000 parts water). A dilute solution of methylene blue is also useful. These dyes are to be dissolved in water from the vessel in which the animals are living.

Stains for General Use.

Picrocarmine is a useful stain for teased preparations. It may be purchased ready made. A drop or two of the stain may be added to water or salt solution on a slide.

Borax Carmine.

This is the most useful stain for small transparent pond animals which have been killed with corrosive sublimate solution or Carnoy's fluid (see below), and is of great service for general use in staining moderately large specimens. It is generally made up in alcohol, and consequently tissues to be stained must previously be soaked in 75% alcohol before placing the stain on them. It can be purchased or made up by boiling six grammes of finely powdered carmine and eight grammes of borax (mix both up well) in 200 c.c. of distilled water. After cooling add an equal volume of 96% alcohol, stand 24 hours and filter. It is necessary to overstain in borax carmine solution, and this may take a day or even longer, and then carefully to differentiate by taking the stain out in 70% alcohol containing 0·1% of Hydrochloric Acid. The action of this must be watched; the stain may take hours to be withdrawn or it may be a matter of much less time. When sufficiently destained,

the tissue must be rinsed with 70% alcohol (without acid) to stop further action. The preparation may be taken down to water and mounted in glycerine jelly, but usually it is taken up to absolute alcohol, xylol, etc., and mounted in canada balsam.

Ehrlich's Haematoxylin.

This stain takes some time to prepare, but it lasts for years, and is extremely useful for both staining in bulk and for staining tissues. It is made by taking 100 c.c. of water, 100 c.c. of 95% alcohol, 2 grammes of Haematoxylin, 100 c.c. of glycerine, 10 c.c. of glacial acetic acid and alum in excess. Dissolve the haematoxylin in the absolute alcohol and add the other ingredients. Set in a large bottle in the sunlight, and shake occasionally after removal of the stopper for a few minutes and replacing it. As the stain becomes ripe it darkens in colour. The stain will probably have to stand in the light for some weeks to become properly ripe in this country, especially in the winter.

For staining a small Daphnid or other small animal or tissue preparation, it is best to dilute a little of the stain considerably with water or 30% spirit. It is better to overstain slowly (hours or days), in a weak solution, than to use a strong solution. Differentiate by withdrawing the stain with acidified alcohol (few drops only HCl in 70% alcohol). When this has proceeded far enough, remove tissue to ordinary 50% alcohol and down-grade the preparation to water. Leave in changes of tap water until the colour goes blue. Then up-grade through alcohols, absolute, xylol or clove oil and mount in canada balsam.

Sections on slides (see page 469) are stained in the concentrated stain (they should be down-graded to 50% alcohol before going into it). The length of time required varies, and may be from half an hour to 24 hours. Differentiate (watching under microscope) as above if necessary, and take down to tap water as described above. On the up-grade the sections may be counter-stained for a few seconds in eosin in 75% alcohol, and then taken up through

90% alcohol, absolute alcohol, xylol and mounted in canada balsam.

This method may also be utilised very well for a blood smear (see below).

Alcoholic eosin. One part Eosin (alcohol soluble) in 100 parts 75% alcohol. This is used in conjunction with haematoxylin for staining sections and smears.

EXAMINATION OF BLOOD

(*a*) *In the Fresh Condition.*

Take a small drop of blood on the centre of an absolutely clean cover glass (must be free from grease). Drop the cover glass on a perfectly clean glass slide. The drop should spread out between the cover and slide, so that three zones are visible—a central zone rather free from corpuscles, a peripheral zone where corpuscles are rather crowded, and an intermediate zone best suited for examination. (The drop of blood must not be too large—that is, large enough to extend to margins of cover slip.)

(*b*) *Dried and Stained Films.*

Take a drop of blood and place on glass slide near one end. Apply the shaft of a needle to the drop so that the blood spreads along the line of contact. Draw the needle across the slide. This should with practice give a suitable film of blood, which is dried rapidly by waving in the air. When dry, place slide in absolute alcohol for ten minutes for fixation, and again dry by waving. Stain by immersion in Ehrlich's Haematoxylin (find out time required, and experiment with frog's blood first; the red corpuscles are nucleated and comparatively large), wash off stain with tap water and leave in latter for five minutes. Counterstain with solution of eosin and then take up to canada balsam in the usual way.

Examination of Fluids containing Spermatozoa from Sperm Reservoirs of Earth-worm or of Seminal Vesicle of Frog.

Smears of these fluids can be made in the same way as blood smears and eventually stained. It is better, however,

to plunge the smeared slide into a fixative such as corrosive sublimate for half an hour. Wash gently and take up to 90% spirit—leave in this a few hours and then proceed to stain and mount.

MICROTOME SECTIONS

For the most accurate study of tissues and the anatomy of small animals or parts of animals, thin sections cut by means of a microtome are necessary. The Cambridge Rocking Microtome cannot be beaten for general work. With a little care quite good sections could also be cut with the little hand microtome illustrated.

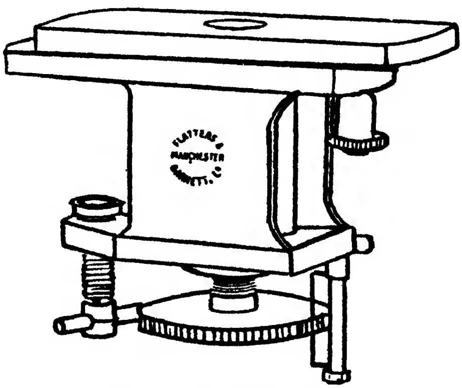


FIG. 236.—Hand microtome.

In order to cut thin sections of animal tissue, it is usual to embed it in melted paraffin wax, so that when cold the piece of tissue is not only supported by a casing of wax, but all the cells are permeated and held together by the same substance. The method in a simple form is as follows :

(1) The following reagents and apparatus, etc., are necessary :

(*a*) Microtome.

(*b*) An arrangement for keeping wax melted at a definite temperature. An incubator is easily the best, but almost as good and much cheaper is a little water bath.

(*c*) Paraffin wax—melting-point 52° C.

(*d*) Absolute alcohol.

(*e*) Pure spirit (96%), from which solutions diluted with water are made up, having strengths of 30%, 50%, 75% and 90%.

(*f*) Benzol (or xylol).

(*g*) Various fixatives and stains.

(2) Before proceeding to embed the material, it is necessary to kill the tissue or small animal to be examined, in such a way that it will not only be as little changed as possible in structure, but will also resist the action of the reagents to be used later upon it. This process is known as fixation. If a frog be killed quickly with chloroform, it does not follow that the muscles or other cells in the body are dead. A piece of the tissue to be investigated must be quickly cut out and placed in a fixative. Use a piece of the frog stomach for a trial. **Fixation**

(3) *Fixatives.* The use of these is also necessary for tissues and small animals which are to be stained and mounted without sectioning (see page 457). Only a few are given here. For details of others refer to that useful handbook of methods—*The Microtomist's Vade Mecum.*

(*a*) 4% solution of formaldehyde. (The solution sold is about 40%, so that it is necessary to take 10 parts of this to 90 of water.) This is a simple fixative, but staining may be difficult after it. It is useful for tissue which becomes too hard to cut after most other fixatives. The tissue can remain in formalin for some time (the longer the more difficult the staining afterwards). It is recommended to neutralise the formalin before using by adding borax.

(*b*) Carnoy's fluid. To be made up as required: Absolute alcohol, six parts; Glacial Acetic Acid, one part; Chloroform, three parts. This is a very useful and quick general fixative. It should not be allowed to act too long. For a *small* piece of muscle, or frog's stomach, fixation should be complete in five hours. This fixative has the advantage that no washing out is really necessary, and the tissue can go on straight into absolute alcohol. If it is to be kept some time, a change or two of less concentrated spirit is desirable.

(*c*) Corrosive sublimate mixtures. Use saturated solution of mercury bichloride (in distilled water). It may be used alone or with the addition of one part per 100 of glacial acetic acid. This is a good general fixative. It must be remem-

bered that the solution is an *intense poison* (handle with care and don't place metal needles or scalpels, etc., in it). It is essential that after the tissue has been fixed (4-6 hours, or less for minute pieces of tissue), the mercury chloride be completely removed. This may be done by washing in many changes (or in running water) or by using alcohol 75% (many changes).

(*d*) Bouin's fluid:

Saturated aqueous solution of picric acid	75 parts.
Formol (as sold)	25 „
Glacial acetic acid	5 „

This is a good general fixative. It is necessary, however, to use it on small pieces of tissue, not for longer than 6-8 hours, and it *must* be thoroughly washed out with changes of 70% alcohol and *never with water*.

These four fixatives should suffice for all general purposes.

Dehydration (4) After fixing the piece of tissue for an appropriate time (the best period is a matter for experiment) and washing with the appropriate fluid indicated above, the piece of tissue is embedded. To this end it must be first dehydrated. If the tissue were washed with water, it is next transferred to 30% spirit until permeated, then 50% until this replaces the 30%, then 75% and then 96% spirit, giving preferably two changes. If the tissue were washed with alcohol, one just proceeds to the next stage of alcohol, that is, 96% if the tissue has been washing in 75%. From 96% spirit the tissue goes into absolute alcohol, which removes the final traces of water. Two changes of absolute alcohol are better than one large quantity. If the method has been carried out properly and the absolute alcohol is really absolute (do not leave about without a stopper, and do not breathe or sneeze into it), the tissue will not produce a milkiness when dropped into the benzol.

The benzol should be allowed to penetrate the tissue and replace the alcohol. Penetration is generally complete when the piece of tissue becomes transparent. When such has taken place (half an hour or longer), change into another small quantity of benzol.

In the meantime the paraffin wax should have been melted and kept melted at a temperature a *little above its*

melting point—56° at the most. If too near the melting point, the wax will solidify whilst the tissue is being placed within it. If too high, the tissue will be made hard.

The tissue is dropped into this with warmed forceps and remains in until permeated. Roughly this should be about twice the time taken to penetrate with benzol. Again, experience with different tissues only comes with practice. The point to be remembered is to leave for as short a time as is possible for thorough permeation. Some tissues will stand a great deal more, although the heat is not good either for their structure or their cutting consistency. It should not be necessary to exceed 2 hours in pure wax.

Embedding. The actual solidification of the tissue in wax is a matter involving certain knacks. To be successful the wax must not be allowed to crystallise, and this will take place if it cools slowly. Many students try to cool the wax quickly *after they have allowed it to go cold*! The author uses the following method. Smear a small watch glass (choosing rather deep ones) with glycerine. Have a dish of quite cold water by your side. Pour *hot* wax (at least 56°, and it will not harm if it is 58°) into the watch glass. Quickly place the tissue in *with warm forceps.* Note the way it is lying, and if necessary put into position with a warm needle. Hold the watch glass on the surface of the cold water (but take care not to let the water run over the top) and blow softly on the surface of the wax. As soon as a pellicle has formed, carefully immerse the watch glass and let it go to the bottom. Leave for the wax to solidify. The disc of wax will come away from the watch glass quite easily when cold if the latter has been smeared with glycerine.

In order to remember the position, a line may be scratched on the surface of the wax with a needle just after immersion to indicate the plane in which the sections must be cut.

(5) *Cutting Sections.* Take the disc of wax and cut it away until the object is left enclosed in the middle of a small cube or rectangular prism (see Fig. 237). It is advisable to have the tissue with an equal amount of wax on each side. Fix the block on the microtome by melting

a piece of wax on the holder of the latter (with an old knife blade made hot in a flame) and placing the block down on it in the correct position for cutting. Cool under tap, and if firmly fixed insert the holder in the microtome and proceed to cut sections. Paraffin sections are cut dry. The thickness of the sections can be varied on most microtomes.

There are many knacks in section cutting, and it is best to practise on something which should cut easily. A section of frog stomach should present no difficulties. If the sections and tissue break as the razor passes over and the razor is really sharp and set at the correct angle, the tissue has not been fixed properly; the fixative has not been thoroughly washed out; or the subsequent treatment has been improperly carried out; or the wax may be too hard (melting-point too high).

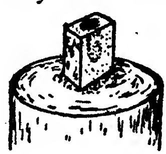


FIG. 237.—Block of wax with object embedded ready for sectioning.

Treatment of Sections after Cutting.

The thin sections are placed on a film of distilled water which has been deposited by means of a pipette on an ordinary well-cleaned object slide previously smeared *thinly* with egg albumen mixture. The albumen mixture is made by shaking up thoroughly 50 c.c. of white of egg, 50 c.c. of glycerine and 1 gramme of salicylate of sodium. Filter and keep in stoppered bottle. Care must be taken not to have too much of this. It is to make the sections stick to the slide. It is best to rub it over and off with the finger until a mere thin film exists. Following this, one just covers the slide with the distilled water and floats the sections on. Then gradually warm the slide. This must be done exceedingly carefully, so that the wax does not melt. The heat causes the sections to extend themselves. Set the slides away in a place sheltered from dust overnight (the water dries off). When thoroughly dry the wax is removed by placing the slides of sections in a bottle of benzol for

about ten minutes (or turpentine is cheaper and as good). The benzol is then removed by placing the slides in absolute alcohol. From this one passes into 96% spirit, and so on down to water, or to a weaker spirit if the staining solution is a spirit stain. It is most convenient to have a series of wide cylindrical tubes or jars which will take the slides and have all the solutions in order (see Fig. 238).

Staining of Sections.

There are almost countless methods for staining, for special purposes. The most satisfactory simple plan is to

Fig. 238.—Set of jars with solutions for the treatment of micro-preparations (see text).

stain the nuclei with one stain and the cytoplasm of the cells with another. We have already mentioned one method, using Ehrlich's haematoxylin and eosin (see page 462). Another method is to use the formula known as Heidenhain's haematoxylin. The following solutions are required :

$2\frac{1}{2}$% solution of iron alum in distilled water.
$\frac{1}{2}$% solution of iron alum in distilled water.
1% solution of haematoxylin in water, containing 10% of alcohol.

The sections are taken down through the alcohols of various strength to water, and then placed in the $2\frac{1}{2}$% solution of iron alum for some hours, overnight will do. The slides are then washed carefully with water and

placed in the stain for half an hour or longer. (The iron alum solution is a mordant.) The result of this will probably be that all the sections are stained a dense black. They are rinsed with water and then dipped into ½% solution of iron alum and periodically watched, after rinsing the iron alum off with water, under the microscope (low power). The iron alum removes the stain and differentiates as it does so. Stop when the colour is removed from almost all but the nuclei. Immerse the slides in tap water and leave in, with constant changes (or running water), for half an hour. Then pass up through the 30% alcohol and 50% to the 75%. From this immerse in a bottle of alcoholic eosin stain :

1 part Eosin (alcohol soluble—not water soluble eosin).
100 parts 75% alcohol.

The sections should stain in a minute or less. (Formalin tissue may require longer.) Rinse the stain off quickly in 75% alcohol and quickly pass up into 90%, absolute alcohol, the benzol, and finally add a thin film of canada balsam on the sections and cover with cover glass.

The whole method is tabulated below :

Tissue (living)
↓
fixative
↓
wash out fixative
↓
take through alcohols to
↓
90% spirit
↓
absolute alcohol
↓
benzol
↓
paraffin
↓
cut sections and place on slide
↓
(next column)

remove wax by means of benzol or turpentine
↓
absolute alcohol
↓
90% spirit
↓
75%
↓
50%
↓
30%
↓
water
↓
iron alum 2½%
↓
haematoxylin
↓
(next column)

iron alum ½%
↓
water
↓
30% spirit
↓
50%
↓
75%
↓
eosin stain
↓
75% spirit
↓
90%
↓
absolute alcohol
↓
benzol
↓
canada balsam

Instructions for Dissection and Practical Work on Common Types.

Specimens should be obtained from ponds by gathering large quantities of weed, bringing back in pond water and setting up aquaria. Carefully examine the weed and walls of the aquarium for *Hydra*. They can be kept, and will breed and flourish if given abundant supplies of appropriate food. The aquarium should contain pond water (unless experiment shows that they will stand tap water). Small aquaria, even glass tumblers, will suffice. The *Hydra* should be given abundant supplies of Daphnids or *Cyclops* twice a week and the excreta removed and the water changed frequently. Small pieces of pond weed may be used for aeration of the water. The temperature must not be too low. **Hydra**

Note the movements of the living animals (Fig. 112). Place specimen in a little water in a watch glass and add small living crustacea. Note the paralysing effect of contact with the extended Hydra tentacles (this does not always happen). Observe method of feeding.

Mount a specimen in water on a glass slide, supporting the cover glass over it on broken pieces of cover slip so that the *Hydra* is not compressed too much. Note the structures depicted in Fig. 38. Run a little 1% methylene blue solution under the cover slip. A drop should be placed at one side and blotting paper brought to the other in order to cause a current to flow under the cover glass. Observe the shooting out of the threads from the thread cells or nematocysts.

If *Hydra* is killed on a microscope slide by running a little 1% acetic acid (preferably containing a little methylene blue) over it, the cells will readily separate after about five minutes in the mixture. Wash away the acetic acid with water, and then apply a cover slip carefully and tap on it. The cells will be separated and nematocysts, etc., readily seen.

If specimens can be encouraged to flourish in aquaria, the development of testes and ovaries and the production of eggs should be observed (see page 365).

The earth-worm

Choose large worms only, and see that an obvious clitellar region is present. The earth-worms may be killed for dissection with chloroform. It is also possible to kill them satisfactorily by placing in a little water and adding spirit gradually during two hours until the strength is about 10%.

Examine the external characters (Fig. 189). Rub the finger gently along the body both ways, and note the resistance of the setae. Pin the animal down under water with its dorsal surface upwards (the darker coloured surface) and slit up the body-wall along the middle line.

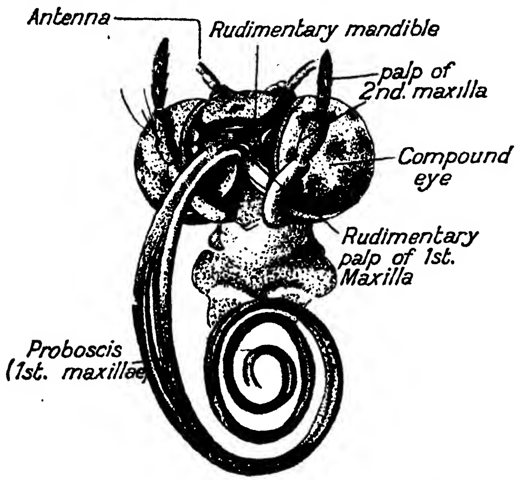


FIG. 239.—Head of butterfly. (After Pfurtscheller.)

(Do not put the foremost pins in anterior end, but at sides of third and fourth segments. This will preserve anterior end of nervous system.) Carefully slit through the septa so that the sides can be pinned out flat. Note the structures shown in Figs. 136, 174, 188. Remove alimentary canal to one side or cut out except pharynx, and look for nervous system and reproductive organs. Carefully expose the nerve ring round the pharynx at anterior end. Dissect out carefully a nephridium and mount in salt solution and examine under the microscope (Fig. 175). Cut a thick hand section through another worm (preferably one hardened by preservation in spirit). Take it up

through grades of alcohols, clear in clove oil and mount in canada balsam.

The cabbage-white butterfly

The butterfly should be bred in the laboratory. The method has already been given and also illustration of the external anatomy. Particular note should be made of the differences between the head of the caterpillar and that of the adult butterfly (see Fig. 239). Examine wings for scales.

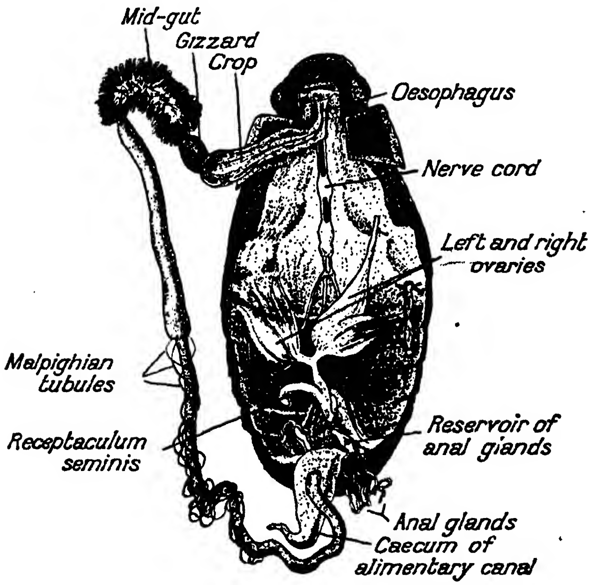


FIG. 240.—Female *Dytiscus* dissected to show general anatomy. (After Röseler and Lamprecht.)

Dytiscus—the water beetle

To be obtained from the ponds in spring and summer, or possibly could be ordered through laboratory attendants of zoological laboratories in universities. Should be examined living in small aquaria.

Note on living animal. Movements. Structure of appendages. Collection of air from surface between wing covers and dorsal body-wall. Note action of antennae and jaws during feeding. Feed upon small aquatic insects or larvae.

Kill by enclosing in small space with a few drops of chloroform. Examine external characters. Note limbs,

especially modified front legs of male with sucking discs. The male holds on to female with these. Note swimming feet (3rd pair). (See Fig. 115.)

Dytiscus (cont.)

(Mount external parts of animal—legs, mouth parts—by removing all water by soaking in changes of spirit and absolute alcohol, then clearing in xylol and mount in canada balsam.)

Examine dorsal surface of body under wings. Note stigmata (openings for air). Cut round one of stigmata and mount as directed for limbs above. Examine head with hand lens, and note mouth appendages. Examine eye with hand lens.

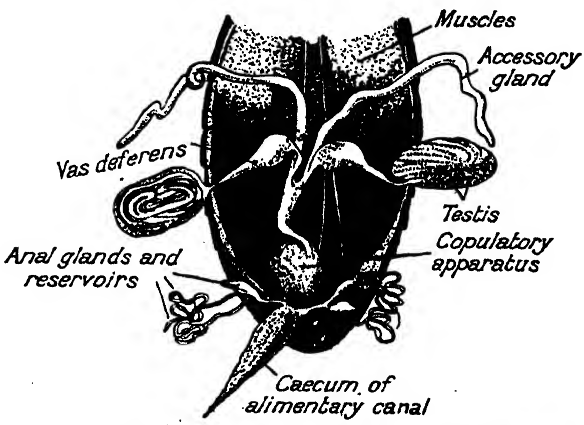


FIG. 241.—Male *Dytiscus* dissected to show reproductive organs. (After Röseler and Lamprecht.)

Dissection. Specimens which have been freshly killed must be used. Beetles and most insects with thick cuticle do not preserve for dissection. Hold animal in left hand and carefully remove wings, and then cut away the dorsal body-wall. After this has been done fix the animal down with pins in a *small* tray with paraffin wax. An old large size blacking tin with a layer of wax melted into it is excellent for dissection of small objects. The beetle may also be fixed to the wax by melting the wax round it with a hot needle; to do this it is necessary that the beetle's lower surface be dry.

Note heart immediately below dorsal cuticle. Dissect

carefully with needles (excellent dissecting instruments for fine objects can be made by filing surgical needles or gramophone needles into the form of sharp-pointed and blunt-ended scalpels and mounting in wooden handles), and expose organs of the body cavity as seen in Figs. 240 and 241. Note and mount microscopic preparations of tracheae (see page 116).

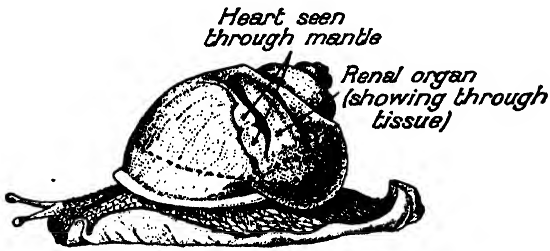


FIG. 242.—Snail (*Helix pomatia*). Left view after shell has been removed. The dotted line indicates position of cut to give Figure 243. (After Röseler and Lamprecht.)

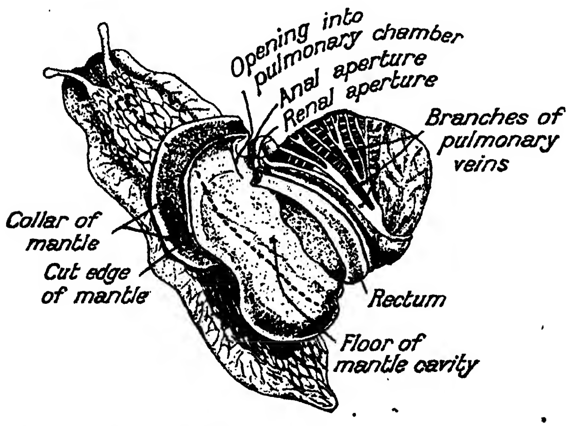


FIG. 243.—Snail from above with pulmonary chamber opened up and roof deflected to right. (Dotted line in position for cut to open up body cavity.) (After Röseler and Lamprecht.)

Examine living specimens. They can be kept in glass jars (large rectangular accumulator jars make excellent aquaria and vivaria); if provided with ample supplies of fresh leaves and the air be kept moist. Note movements by allowing snail to crawl over glass plate, and invert so that lower surface can be watched (see page 223). The snail

Snail *(cont.)* Note movements of tentacles, feeding habits, and on right side the respiratory aperture, which is periodically opened and closed.

To kill for dissection, put a number of snails two days or so before being wanted in a wide mouthed glass-stoppered bottle containing about one litre of cold *boiled* water, and keep in a warm place. The stopper must be placed in

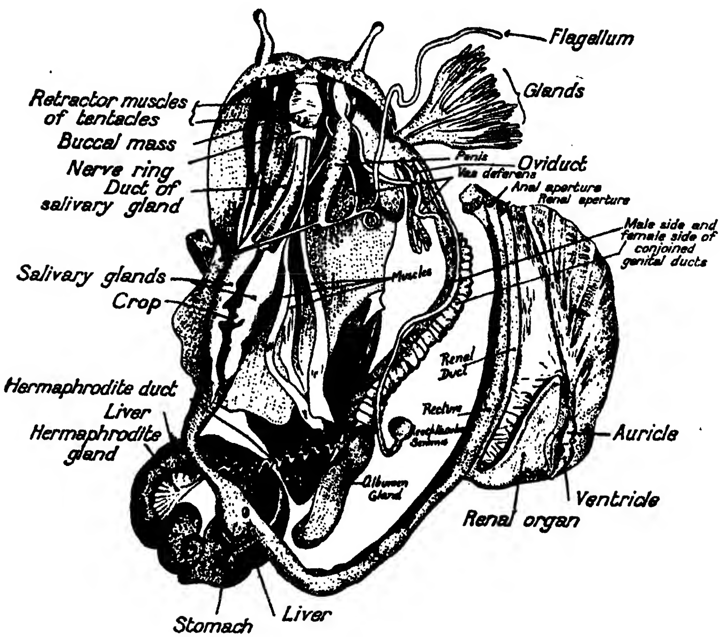


FIG. 244.—Snail dissected to show general anatomy. (Modified after Röseler and Lamprecht.)

so that no air bubbles remain in the bottle. If such a jar is not at hand, use a glass cylinder or jam jar, and close with a glass plate so that no air is enclosed. The snails will extend themselves, and after 48 hours or earlier, if they are dead, should be thrown into 50% alcohol. First remove shell piece by piece until the animal is completely exposed. Note external characters depicted in Fig. 242. Cut along dotted line and expose pulmonary chamber and parts indicated in Fig. 243. Now cut along the dotted line of Fig. 243 and pin back. Expose the organs of the body

cavity, and carefully arrange so as to give the view depicted in the illustration (Fig. 244).

The common mussel (*Mytilus edulis*)

Live specimens of the mussel can be purchased in most towns in England and Wales. The student should make a salt-water aquarium, either by using sea water or artificial sea water made as follows:

45 ozs. common salt.
$3\frac{1}{2}$ ozs. magnesium sulphate.
$5\frac{1}{4}$ ozs. magnesium chloride.
2 ozs. potassium sulphate.
$13\frac{1}{2}$ gallons fresh water.

Dissolve the salts separately in as much water out of the whole as is necessary for their solution. Then mix and let stand for a week or two in good light and in large accumulator jars covered over with sheets of glass.

Place a specimen in a small quantity of the sea water in a glass crystallising dish, and note the gradual opening of the shell. Demonstrate the respiratory currents by bringing finely powdered carmine suspended in a little of the aquarium water before the free margins, especially where indicated in Fig. 57.

Kill a mussel by dropping into hot water, but do not boil the animal. Separate one valve of the shell by running a small old scalpel blade close against the inner surface of this valve (start at the narrow end), and cutting off the attachments of the soft tissues. The general anatomy is exposed at once. Find the structures depicted in the illustration (Fig. 57). Cut a piece of a gill from another specimen which has been opened, without killing the animal, and examine it under a microscope in some of the liquid from within the shell. Note the cilia. A piece of gill should be fixed (see page 121) and stained. A piece could be mounted whole and another piece prepared for microscope sections (see page 466).

Examine a drop or two of blood from a living specimen under the microscope, and note the colourless corpuscles which protrude pseudopodia. Run a little blood into a watch glass, and note how the corpuscles collect together in groups visible to the naked eye (see page 151).

The crayfish

In most parts of England crayfish are becoming exceedingly difficult to obtain. They should be ordered and examined in spring and summer, and not sought for during the wet winter months when streamlets are flooded. The lobster can be used instead, but this animal will prove expensive if many large specimens are used. The crayfish is most desirable as a type, because it can be conveniently examined alive, and it is also necessary in the living condition in order to obtain digestive juices for the experiments described on pages 62 and 66. Supplies may be obtained from the zoology laboratory attendants at universities. Crayfish are said to be obtainable in the banks of streamlets in the Thames valley and also in the Ribble district. They can also usually be obtained from the Midland Fisheries Co., Nailsworth, Gloucester.

To keep alive for a short time in an aquarium the animals should be in water which is not deep enough to do more than cover them. They do not usually live long in captivity unless special care is taken, and generally this is not the case. Note movements and test for the respiratory current (see page 112).

See pages 76 and 78 for experiments on digestion.

For examination kill the animal by dropping into boiling water and pulling out again immediately, or by using a little chloroform enclosed in a small space with the crayfish. The animals should not be preserved for long before dissection. Note the features named in the illustrations, and for examination of the appendages remove them from the body, proceeding from behind forwards. Note the limitation of movement at each joint of claw and the direction of same (see page 171).

Note opening of so-called auditory sac at base of antennule (see page 479). Cut the sac out altogether and examine under microscope (see page 288). Dissect under water from the *dorsal* surface, removing carefully first the dorsal chitinous exoskeleton. Note the structures rendered visible as one proceeds deeper, and finish by dissecting clear the nervous system which is close against the ventral surface. The nervous system is very easily pulled out or broken in

removing the muscles of the abdomen. (The alimentary canal should be removed for separate investigation of the so-called stomach—see page 77 and Fig. 27 for description.)

Begin the dissection of the nervous system in the abdomen, where it is only covered by muscle. In the thorax it

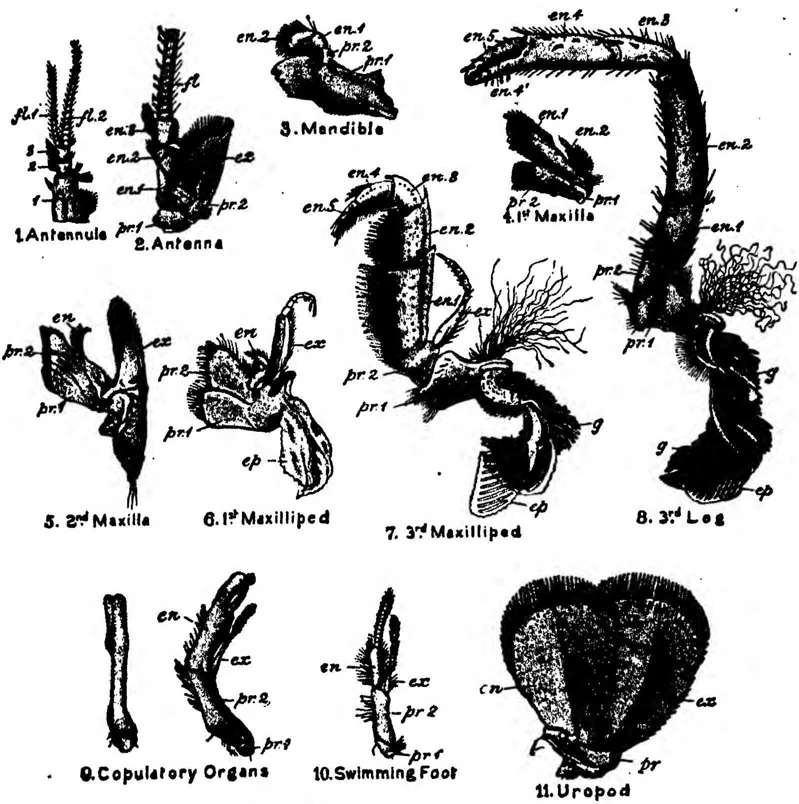


FIG. 245.—Appendages of crayfish. (After Huxley.)
en. endopodite; *en.* 1 and *en.* 4, joints of endopodites; *ep.* epipodite; *ex.* exopodite; *fl.* 1 and *fl.* 2, so-called flagella of antennule; *fl.* flagella; *g.* gill; *pr.* 1 and *pr.* 2, parts of protopodite.

runs within an internal skeleton, which must be cut with strong scissors. Follow the nerves forward round the œsophagus to the large supra-œsophageal ganglion.

Take a crayfish which has been hardened by preservation in formalin (open up window in carapace before placing in preservative, otherwise the latter will not penetrate to the interior sufficiently rapidly), and make an incision with

scissors and strong scapel the smallest amount to one side of the middle line both dorsally and ventrally. Using a mounted safety razor blade, completely divide the crayfish into two halves. Review study of anatomy, and in particular note position of muscles.

The dogfish Dogfish can be obtained from the Biological Station, Plymouth; Biological Station, Port Erin, Isle of Man; and orders through zoological laboratories of several of our universities.

Examine the external characters. See Figs. 26, 47, 83 and 84, and refer to pages 175 and 228.

Strip off a piece of skin to examine muscle segments (myomeres), and examine scales and teeth. Note the apertures of the mouth, the nostrils connected with the mouth by grooves, the gill slits, spiracles, cloaca, abdominal pores, and the small openings of canals containing sense organs.

Fasten the fish down on its back on a wooden tray by nails through the pectoral fins, and cut through the ventral body-wall along the middle line from the pelvic girdle to the pectoral girdle, which can be felt between the pectoral fins. Continue this incision backwards to the side of the cloacal aperture so as not to injure the cloaca.

Make transverse cuts at the ends of the longitudinal cut, so that the two flaps of body-wall can be reflected back to each side. Note the organs marked in the illustration. Slit up the intestine and wash out to expose the spiral valve.

Cut in the same line from the mouth backwards, and expose the heart by carefully cutting through the pectoral girdle (feel it with fingers first), the gill clefts and gills as seen in Fig. 26.

Remove the muscles carefully, and follow the conus arteriosus and ventral aorta forward from the ventricle.

Cut through the jaw and gills on one side, and turn the whole of the floor of the mouth outwards and to one side. Carefully take away the lining of the roof of the mouth, and the blood vessels from the gills should be exposed. These Efferent branchial vessels meet in the middle line to form the Aorta which conveys blood to the viscera.

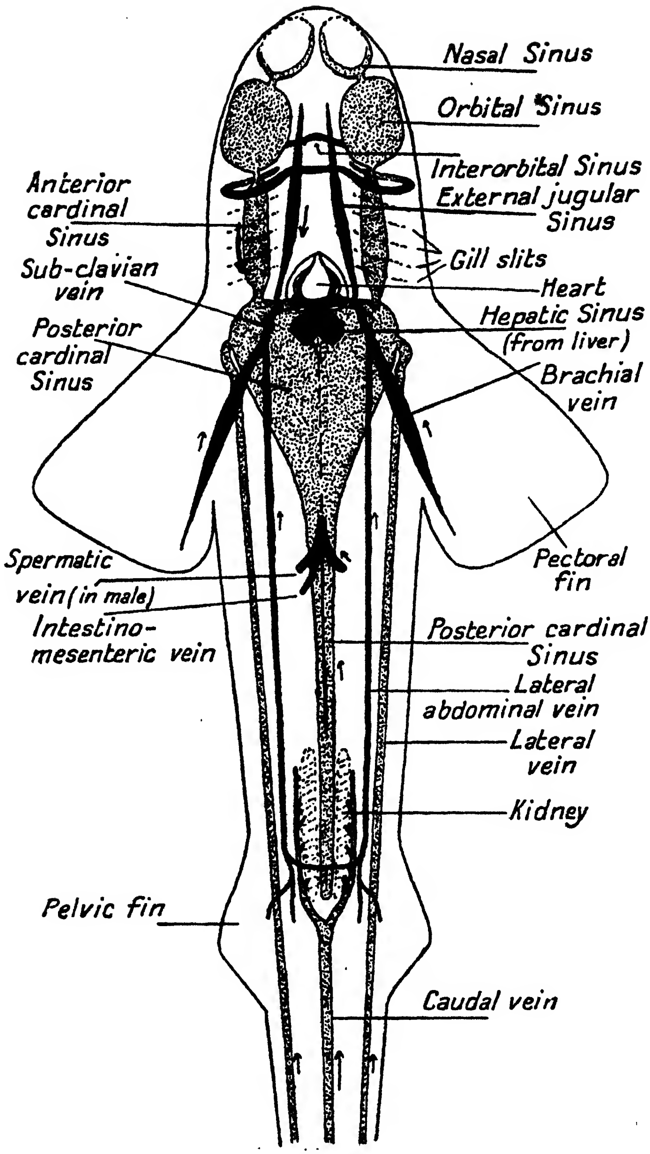


FIG. 246.—Diagram of venous system of dogfish. (From O'Donoghue.) The more dorsally situated vessels are stippled and the more ventral ones black.

Turn the dogfish on its ventral surface and cut through the skin round the eye. Pull out the eyeball and note the eye muscles and nerves. Remove eye altogether by cutting through the eye muscles and optic stalk *close* to the eyeball.

Remove skin from dorsal surface of head between eyes. Shave away the cartilaginous roof of the skull until the

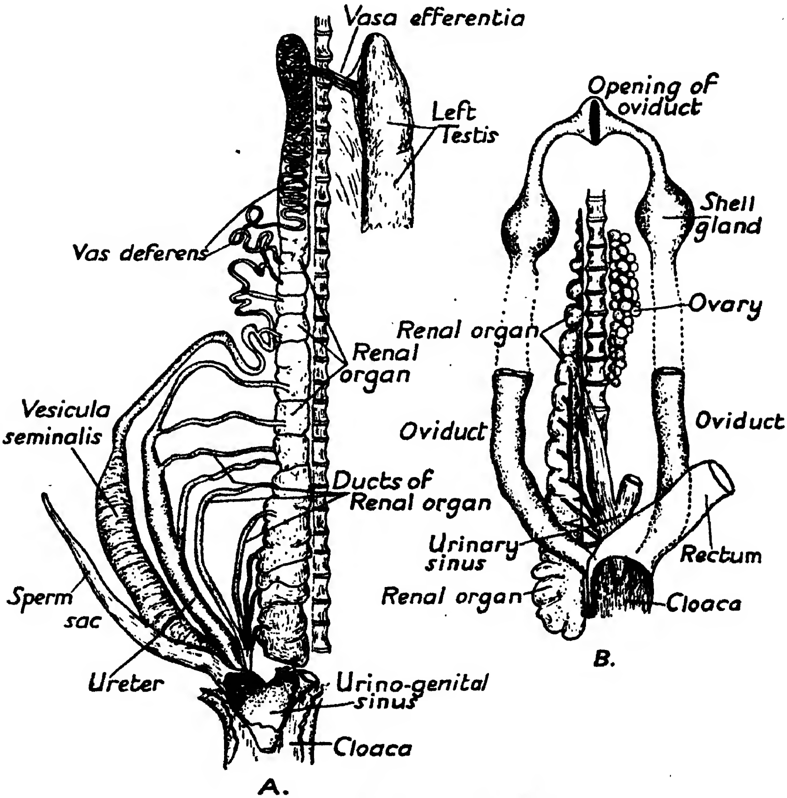


FIG. 247.—Renal organs, etc., of dogfish.
A. Male. *B*. Female.

brain is exposed. Continue to enlarge the aperture, and completely expose the brain and follow nerves as illustrated in Fig. 147. Cut nerves and remove brain. Note ventral view.

Cut off the tail region behind the cloaca, and examine cut surface for vertebral column, spinal cord and caudal blood vessels enclosed in arches of skeleton.

The skeleton can be examined by taking a spirit specimen, dipping in almost boiling water for a few minutes, and then cleaning up by removal of soft parts.

Examine the frog in a small vivarium and note the movements. Place in water and observe how it swims. Watch the floor of the mouth for breathing movements (see page 107). The frog

The animal should be killed by placing in a closed jar with a little chloroform.

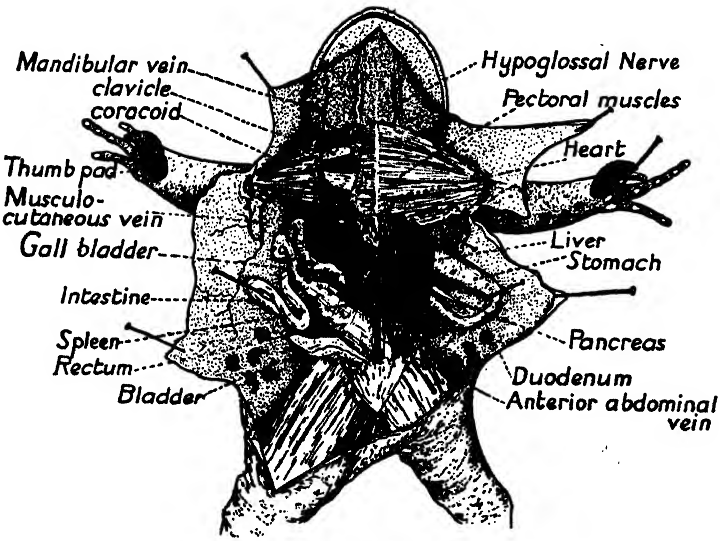


FIG. 248.—General dissection of male frog.
Note how the anterior abdominal vein is left in place in the middle line. The pectoral muscles are stripped off on the left side to show the clavicle and coracoid bones which are to be cut on both sides for removal of sternum and exposure of heart.

Note external characters and apertures on the body surface. Open the mouth and observe internal structures (see Fig. 21).

I. Place frog on back in dissecting dish, and pin down the hands and feet. Do not stretch the arms unduly. (Dissect under just sufficient water to cover the animal.) Cut first the skin only (it is loose) along the middle line of the belly and along the limbs, and pin back or remove. Note the blood vessels of the skin, which acts as an accessory respiratory organ. The spaces between the skin

and the underlying muscular body-wall are subcutaneous lymph spaces. Note the muscles and a blood vessel in the middle line.

II. Pinch up and cut through the muscular body-wall along one side of the vein showing in the mid-ventral line (anterior abdominal vein). Do the same on the other side of this vein, so that a narrow strip of body-wall is left in the

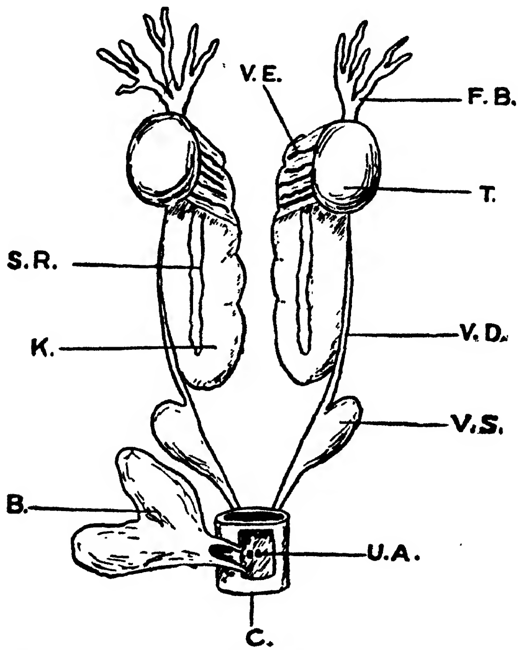


FIG. 249 A.—Diagram of urinogenital system of male frog. (From O'Donoghue.)

B., bladder; *C.*, cloaca; *F.B.*, fat body; *K.*, right kidney; *S.R.*, suprarenal body; *T.*, testis; *U.A.*, urogenital aperture; *V.D.*, vas deferens; *V.E.*, vas efferens; *v.s.*, vesicula seminalis.

middle line. Carry the incision forward to the pectoral girdle (feel). Make cross cuts to each side and pin back the flaps of body-wall and note the abdominal viscera (Fig. 248). Pin the alimentary canal (Fig. 22) to one side. Note the reproductive organs and blood vessels and spinal nerves not easily seen before.

III. Remove the muscles covering the pectoral girdle, so as to expose the bones (see Fig. 95). Cut through clavicle and coracoid on each side near the shoulder joint

with sharp strong scissors. Lift up sternum in the middle and carefully detach it, with the portions of the pectoral girdle on each side, from the underlying tissues. Great care must be taken, for the heart is immediately underneath and the blood vessels may easily be cut or torn. After the sternum has been removed the pins should be taken

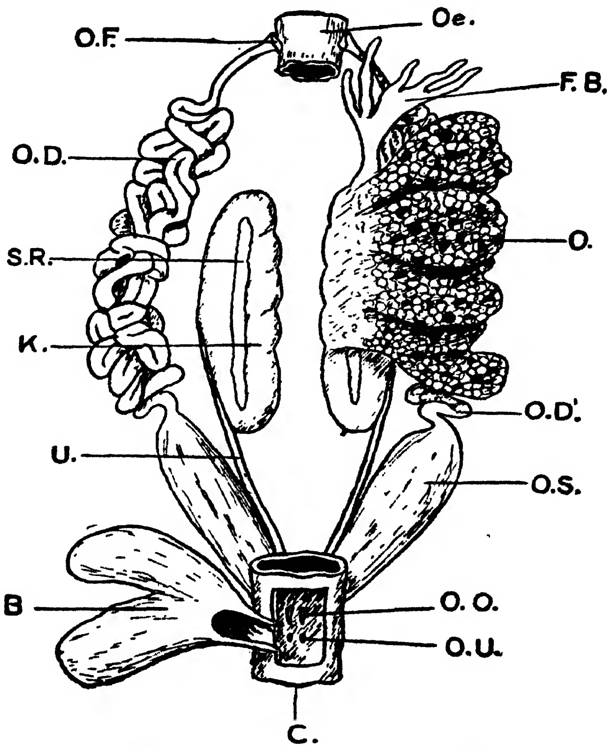


FIG. 249B.—Diagram of urinogenital organs of female frog. (From O'Donoghue.)

B., bladder; *C.* cloaca; *F.B.*, fat body; *K.*, right kidney; *O.*, ovary; *O.D.* oviduct; *O.D.*, lower end of left oviduct; *Oe.*, oesophagus; *O.F.*, oviducal funnel; *O.O.*, opening of ovisac; *O.S.*, ovisac; *O.U.*, opening of ureter; *S.R.*, supra-renal body: *U.*, ureter.

out of the hands and the arms stretched a little further apart and repinned.

Note pericardium containing the heart. Open it and expose heart clearly. Note lungs and other organs. Trace the arteries and veins from the heart (see Fig. 67). After noting the arteries and veins associated with the alimentary canal, remove this altogether.

Note the aorta and the spinal nerves and sympathetic system at the back of the abdominal cavity.

IV. After completing the dissection of the blood vessels and tracing out the paths of the spinal nerves, turn the frog over on the ventral surface, remove the skin from the dorsal surface of the head, and carefully remove the skull bones to expose the brain. After removal of the skin, one

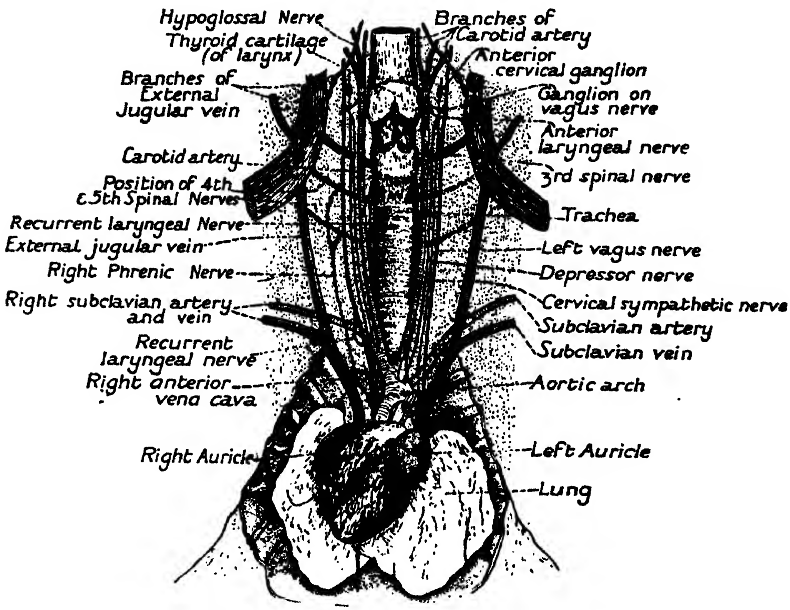
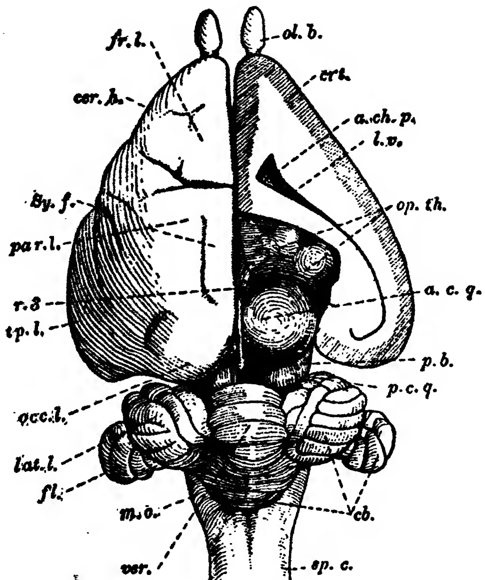


FIG. 250.—Rabbit dissection to show the nerves and vessels of the neck. The vagus, the depressor and the cervical sympathetic nerves lie close to the carotid artery. They are shown slightly separated in the illustration. The 4th and 5th spinal nerves are indicated in dots, and the origin of the phrenic nerve is shown only on the right side.

should see clearly the fronto-parietals (see Fig. 95). Run the blade of a sharp small scalpel once or twice along the middle line between them (take care it does not go through into the brain), and then try to lever one of the bones up. It is easy with patience. The brain lies close underneath and is easily smashed up! Gradually snip away the skull bones to show brain. Sketch dorsal surface (see Fig. 146), and then remove altogether and examine ventral surface. For examination of the nervous system, and especially



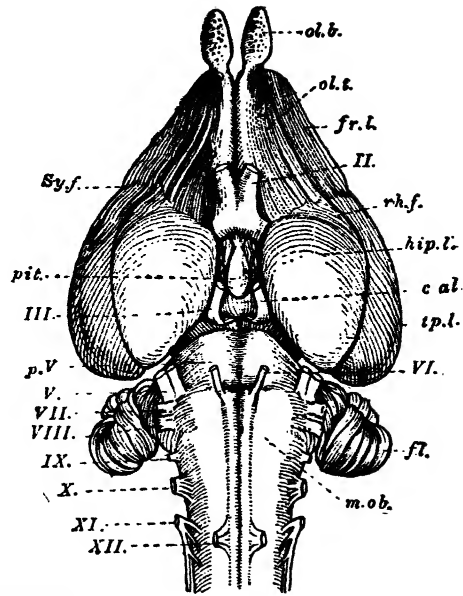


FIG. 251.—Brain of rabbit. (From Borradaile.)

A. From above with part of right cerebral hemisphere cut away.

FIG. 251A.—*a.c.q.*, Anterior corpus quadrigeminum; *cb.*, cerebellum; *cer. h.*, cerebral hemisphere; *crt.*, cortex; *fl.*, flocculus; *fr.l.*, frontal lobe of cerebral hemisphere; *l.v.* lateral ventricle; *lat.l.* cerebellum; *m.o.*, medulla oblongata; *occ.l.*, occipital lobe of cerebral hemisphere; *ol.b.* olfactory bulb; *op.th.*, optic thalamus; *p.b.*, pineal body; *p.c.q.* posterior corpus quadrigeminum; *r.3*, roof of third ventricle; *sp.c.*, spinal cord; *Sy.f.*, Sylvian fissure; *ver.*, vermis.

B. From below.

FIG. 251B.—*c.al.*, Corpus albicans; *fl.*, cerebellum; *fr.l.*, *hip.l.* and *tp.l.* lobes of cerebral hemisphere; *m.ob.*, medulla oblongata; *ol.b.*, olfactory bulb; *ol.t.*, olfactory tract; *p. V.*, pons Varolii; *pit.* pituitary body; *rh.f.*, rhinal fissure; *Sy.f.* Sylvian fissure; II.-XII. roots of cranial nerves.

the brain, specimens should be hardened for some days in strong alcohol.

V. Examine prepared skeleton of the frog. This is best carried out by killing a frog, opening up the abdominal cavity and removing viscera without, however, cutting through any bones. Next remove as much flesh as possible with scalpel and scissors. Dip occasionally into boiling water. Take care not to destroy cartilage (use illustration as guide), and do not pull off the toes.

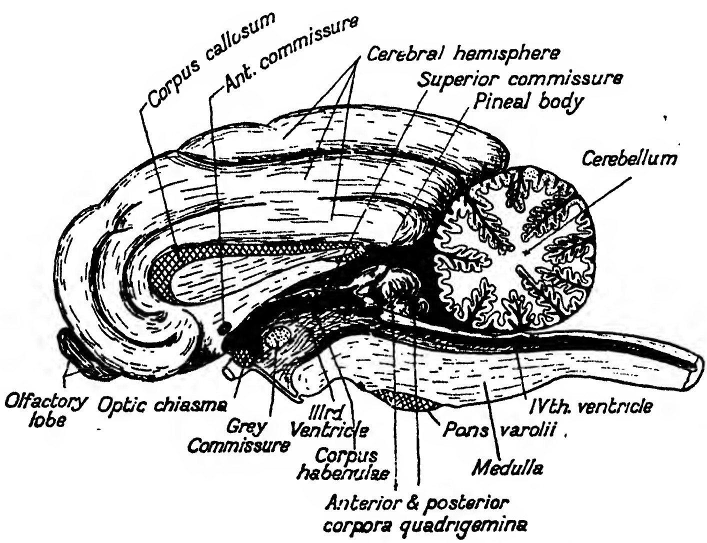


FIG. 252.—Median longitudinal section through brain of sheep. (After O'Donoghue.)

The rabbit The rabbit (lean ones over three months old should be used) should be killed with chloroform half an hour before use.

I. Examine external characters: head (with details), neck, trunk, limbs and apertures.

II. Examine mouth (see Fig. 18), and note teeth, palate, pharynx, aperture of windpipe (glottis). Cut through the soft palate and look for Eustachian tubes (see page 292).

III. Fasten the rabbit down on its back and remove the skin from its neck, thorax and abdomen (cut through the skin only down middle line and separate from underlying

tissue, and reflect back the flaps as far as possible to each side). Make a median longitudinal incision through the abdominal wall and turn flaps also to the sides. This incision will be continued forwards up to the sternum. Note organs of abdominal cavity (see Figs. 17, 70, 194 and 195) and separation from thorax by diaphragm.

Make out the postcaval vein, hepatic portal vein, mesenteric arteries and veins, renal arteries and veins, dorsal aorta, etc. Ligature the œsophagus and cut it through above ligature. Do the same to the rectum and cut below. Double ligature the portal vein with two pieces of thread about half an inch apart and just before it enters the liver. Cut through the vein between the ligatures and remove the alimentary canal and spread out on a board. Note relations of parts and ducts of glands (see Fig. 17).

Ligature the postcaval vein where it enters and leaves liver and remove liver. Examine in more detail the blood vessels left in the abdomen—the termination of the postcaval vein and aorta at posterior end of body.

Examine reproductive organs (see Figs. 194 and 195).

IV. *Dissection of Thorax and Neck.* Remove pectoral muscles and expose ribs. (In dissecting pectoral muscles away, take care not to injure blood vessels to arms.) Cut through ribs carefully on each side of breast bone, working from behind forwards. Do not cut the first (most anterior) rib. Remove the breast bone between the cut ribs. Enlarge the opening into thorax thus made, and now carefully cut through the first rib on each side. There are blood vessels close beneath. Note the pericardium, heart, thymus gland, lungs and diaphragm. Dissect away pericardium, thymus, etc., and lay bare the blood vessels entering and leaving the heart (see Fig. 70).

Make a median incision through the body-wall of the neck and separate back the tissues to either side. Follow forward the blood vessels to head. Note important nerves disclosed (see Fig. 250).

Take out heart and compare with sheep's heart (purchased) (see pages 141, 143).

V. Dissect skin away from one side of head and note glands, etc. (see Fig. 18).

VI. Remove bone from top of head and expose brain. Gradually enlarge hole by breaking away bone with bone forceps and strong scissors. Take out brain and examine (see Fig. 251).

VII. Examine a prepared skeleton of the rabbit (see Figs. 97, 98 and 100).

VIII. Examine sections of elbow joint (see Fig. 91).

APPENDIX

I

FURTHER NOTES ON SOME PROBLEMS IN GENETICS

THE explanation of Mendelian Inheritance depends on the conception that certain definite units are present in the chromosomes, which determine the adult characters. Furthermore, it is based on the conception that these units are present in the fertilised egg and in the cells of the organism developing from that egg, in *duplicate*. Finally it assumes that when the germ cells are formed each one (egg or sperm) can receive only one member of any pair of such factors.

Although in the examples to follow it might *appear* that the adult character is entirely due to one factor, this view must not be admitted. Our examples merely show that the presence of this or that factor, *acting probably in conjunction with many others*, produces certain effects. There are many, many examples which will show that even this simplicity is probably unusual.

I

Backcross

The first cross to be described is what is known as a Backcross. It corresponds to crossing the tall hybrids of page 449 with the recessive parents, the Dwarf pea plants.

We can, however, take an animal example :

Black Guinea-pig (pure for black) × White Guinea-pig

F_1 Black (hybrid) Guinea-pigs.

(All the F_1 generation are black, meaning that black is dominant).

The result of the backcross :

Hybrid black × White Guinea-pig

50% Hybrid Black and 50% White.

The explanation :

Hybrid black guinea-pigs produce germ cells carrying *either* the factor for black or the factor for white, and there are equal numbers of each. The germ cells of the white guinea-pigs have only the one colour factor.

The possibilities at fertilisation, according to the laws of chance, can be shown most easily by setting out the combinations as follows :

Germ Cells→ ↓	Black	White
White	Black White	White White
White	Black White	White White

which is 50% black white, and 50% double white. Those carrying black and white are, of course, black in colour, hybrids like the F_1 generation.

II

Monohybrid Cross without Dominance

Characters do not always bear the relation to each other in development which is indicated in crosses where the F_1 generation hybrid is almost exactly like one parent (the dominant) in appearance. This is shown in the following cross:

Black Andalusian Cock × White Andalusian Hen

F_1 All progeny are *Blue*

Blue Hybrid Cock × Blue Hybrid Hen

F_2 25% Black 50% Blue 25% White.

The explanation is exactly the same as that for the Cross of the Tall and Dwarf pea plants, except that in this hybrid the factors for both black *and* white exert their influence on the coloration.

Dihybrid Cross

III

The crossing of a White Rough-haired Guinea-pig with a Black Smooth-haired Guinea-pig provides an example of a cross in which two pairs of chromosomes are concerned. It is understood in these examples that, unless otherwise noted, the animals crossed are pure bred for the characters concerned. This means that two individuals pure bred for black will not give white progeny when crossed, nor will two rough give any smooth.

The complete results of the cross to the F_2 generation are as follows:

Parents White Rough-haired × Black Smooth-haired

F_1 All progeny are Black and Rough-haired (hybrid)

Hybrid Black Rough × Hybrid Black Rough

F_2 9 Black Rough 3 Black Smooth 3 White Rough 1 White Smooth

(It will be noted from the results that Black is dominant to White and the rough-haired coat dominant to the smooth.)

The explanation of this cross can be set out in the same way as the former example. The hybrid Black Rough-haired parents can each produce four kinds of germ cells, each containing one factor for coat colour and one factor for kind of hair, *i.e.* the eggs contain either B and R, or B and S, W and R or W and S, and the sperm similarly. Setting this out with a square to show the possible combinations, the result is:

	BR	BS	WR	WS→(Eggs)
BR	BR BR	BS BR	WR BR	WS BR
BS	BR BS	BS BS	WR BS	WS BS
WR	BR WR	BS WR	WR WR	WS WR
WS ↓ (sperms)	BR WS	BS WS	WR WS	WS WS

Thus out of 16 possible young, 9 are Black and Rough-haired (but it will be noted that 8 of these are hybrids) ; 3 are White and Rough-haired ; 3 are Black and Smooth-haired and only 1 White and Smooth-haired. (Actually, as may be seen from the above, the only ones which will breed pure are one Black Rough, one Black Smooth, one White Rough and one White Smooth.) It will, of course, be realised that the proportions referred to in these examples are only approximated when large numbers of animals are bred.

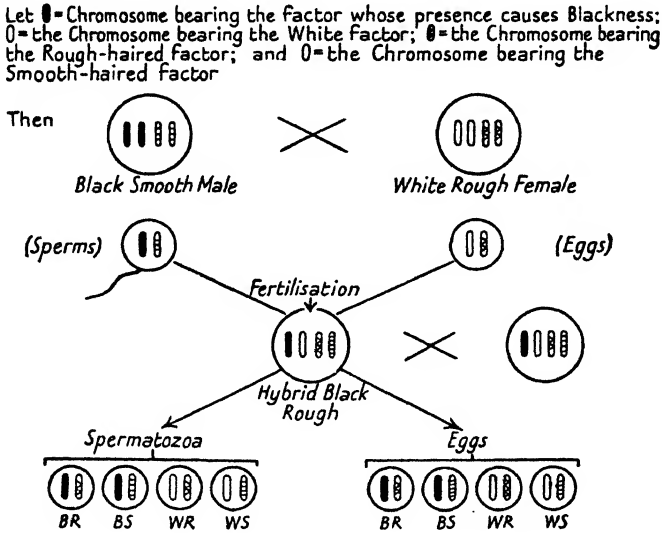


FIG. 253

This example of the Guinea-pig can be illustrated in another way by showing the behaviour of the chromosome mechanism. It is postulated that each chromosome is present in duplicate, and that the factor affecting coat colour is on a different chromosome from that affecting the quality of the hair. For simplicity, we leave out in the diagram all the chromosomes with the exception of those bearing the factors for the characters we are discussing.

The results of these four sorts of gametes being free to fertilise each other according to the laws of chance, gives the F_2 result already shown above.

IV

A more complex example of Inheritance is shown in the following cross (which is an exact parallel of the inheritance of colour blindness in human beings). In the previous examples it did not matter which way the parental cross was made—*i.e.* in the Andalusian fowl example the cock could have been the white bird and the hen the black. In the example now to be described the sex plays a more important part. It is an example of Sex Linkage.

The explanation is that in this insect the factor for eye colour is on a particular chromosome which, when present in duplicate, causes the animal to be female. We say that the female has two X chromosomes,

the male only one X, the other being represented by a Y chromosome which carries no factor for eye colour. The 'genealogy' of the chromo-

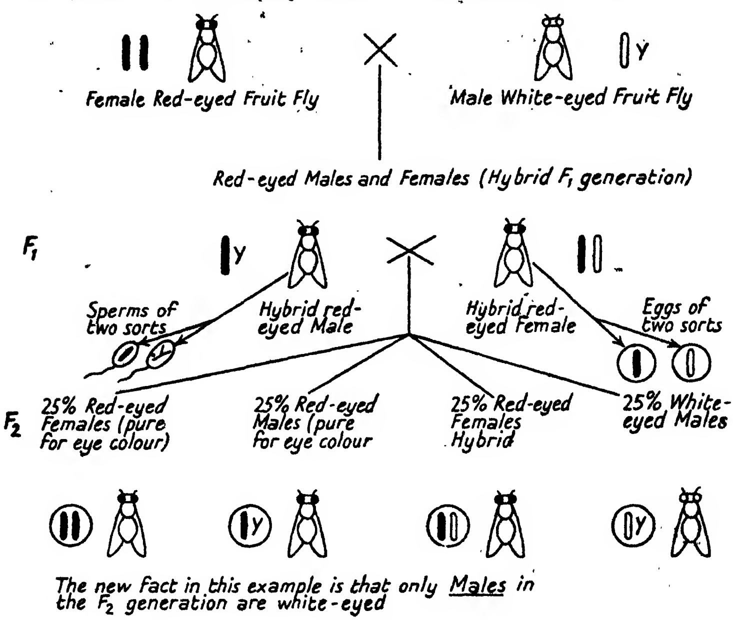


FIG. 254

somes concerned is illustrated (the others being ignored in the diagram). It will be seen from a glance at the F_1 generation that Red-eye is dominant to White-eye. The rest should be obvious.

II
THE EMBRYOLOGY OF THE FROG

Living frog's eggs being most easily obtained, the following notes and drawings are appended to explain details of the early development not given in the text where a hypothetical vertebrate has been discussed. The illustrations show how fertilisation is followed by segmentation (see page 367) but the yolk present at the lower pole of the egg causes the cell divisions to be very unequal. It will be noted that the upper or animal pole of the egg is coloured by black pigment embedded in the protoplasm, the other pole is light coloured. By reason of the heavier yolk the egg floats always with the black pigmented pole uppermost. There is one other thing specially worthy of note. After fertilisation a grey-coloured crescentic region appears on one side between the black and the white regions (Fig. 255, 6.) Recent research has shown that this is the seat of an organising agent.

After a number of regular divisions in vertical and horizontal planes, the segmentation has resulted in an upper region of small cells dividing more rapidly and growing over the larger yolk cells. There is an internal

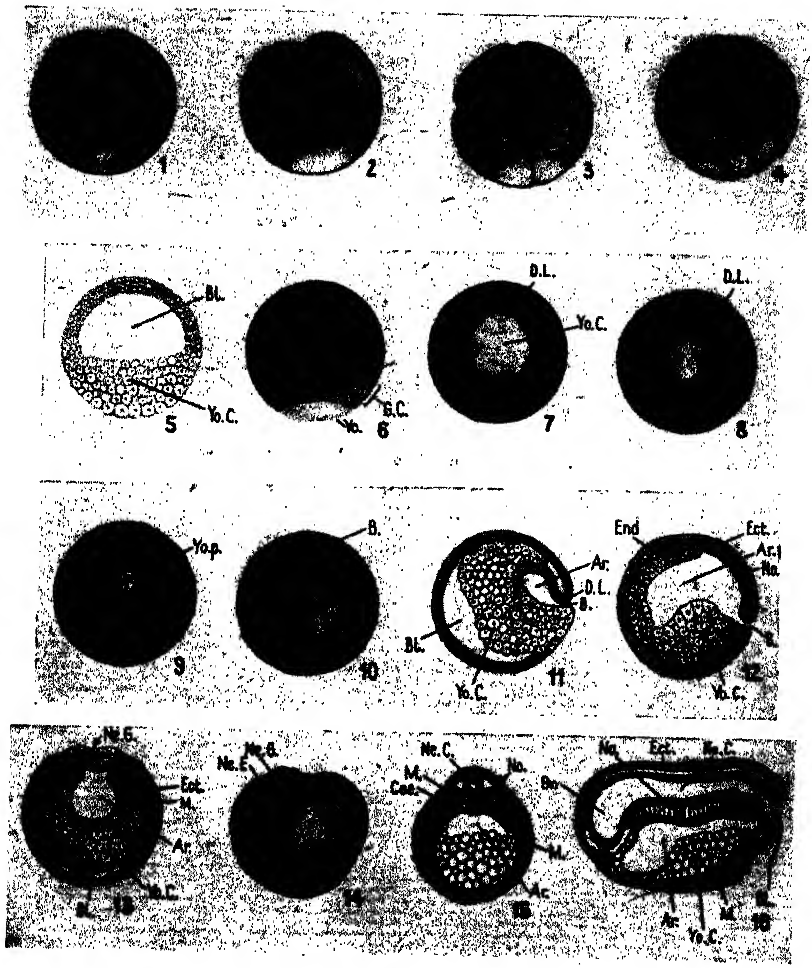


FIG. 255. Embryology of the Frog.

Composite diagram illustrating some of the more important stages in the early Embryology of the Frog.

Nos. 1–4. Segmentation. 5. Vertical section of Blastula stage. 6. Side view showing position of Grey Crescent. 7–10. Stages showing pigmented ectoderm cells overgrowing yolk cells (light) and formation and closure of Blastopore (Mod. after Jenkinson). 11 and 12. Sections through median axis of embryo showing ingrowth at Blastopore and formation of primitive alimentary canal (Ar.). The yolk cells form the floor of this and the roof at the Anterior end. 13. Transverse section through posterior part of embryo shown in 12 (11–13 after Vogt). 14. Neural folds developing. 15 and 16. Transverse and Median sections of same stage in which Spinal Chord and Notochord are definitely laid down. The Neural Canal and the Alimentary Canal are still in communication at the Blastopore.

Ar. Archenteron (alimentary canal); *B.* Blastopore; *Bl.* Blastocoel; *Br.* Brain; *Coe.* Coelom; *D.L.* Dorsal Lip; *Ect.* Ectoderm; *End.* Endoderm; *G.C.* Grey crescent; *M.* Mesoderm; *Ne.C.* Neural Canal; *Ne.F.* Neural fold; *Ne.G.* Neural groove; *No.* Notochord; *Yo.C.* Yolk cells; *Yo.p.* Yolk plug.

cavity filled with fluid (Section shown in Fig. 255, 5.) This stage corresponds to the Blastula of our hypothetical example (page 369). From now on the processes are more difficult to follow. A little 'chink' appears just below the grey crescent, where this borders on the yolk, and deepens so that a flattened cavity pushes inwards. The grey crescent is its dorsal lip. At the surface this chink gradually becomes horse-shoe shaped as it grows inwards, an ever deepening slit, and isolates a 'core' of the yolky cells connected with those which have been completely overgrown and hidden by the small pigmented cells. Sections show how the 'chink' gradually extends inwards (Fig. 255, 11 and 12). Its progress is partly due to division of the small cells at the dorsal lip and partly to an infolding of this surface layer which is carried inwards by growth.

The crescentic chink has become a circular chink surrounding the little plug of yolk cells (Fig. 255, 9). Finally even these are no longer seen and then there is nothing left but a tiny vertical chink (Fig. 255, 10). The chink represents the place where the blastula wall bulged in, in our example (page 370), to form the gastrula. It is the **Blastopore.**

The white pole of the embryo has thus become overgrown by the dark, the yolk cells having been pushed inside. And a section at right angles to the blastopore now shows that the crescentic chink leads into a cavity which has pushed itself right forward (Fig. 255, 12). The original cavity—the blastocoel—has become smaller and smaller (Fig. 255, 5 and 11).

We can now distinguish an outer wall of several small layers of cells —the Ectoderm—and the larger, more irregular yolky cells, the Endoderm cells, the larger of which form the floor and sides, and front end of the new cavity, which is really the beginning of the alimentary canal.

From now on we can trace the beginning of the characteristic organ systems of the tadpole. Between the Ectoderm cells of the outer layer and the Endoderm cells a third layer has already made its appearance. This has been formed in a most interesting way by the cells of the ectoderm which were once on the exterior surrounding the blastopore when the yolk plug was visible (Fig. 255, 8).

Some of the yolk cells form the roof of the anterior end of the alimentary canal. These and the yolk cells of the sides and floor of this cavity become the Endoderm.

The cells of the grey crescent region and the dorsal lip of the blastopore have moved towards the slit and been carried inwards—the direction of the movement is shown by the arrows (see Fig. 255, 8). Along the middle line of the roof of the alimentary canal in proximity to the blastopore, the roof is formed by a strip of such cells which have been carried inwards from the dorsal lip of the blastopore and at right angles to it (Fig. 255, 11). This strip gives rise along the middle line to a rod of cells which become differentiated to form the *Notochord*—(see page 371) the beginning of the skeleton.

At the sides of the Notochord the cells which have grown in from the blastopore margins separate as the Mesoderm, which extends sheet-like between the Ectoderm and the Endoderm, completely surrounding the latter. Later it splits into two definite layers (see Fig. 255, 15) and the cavity between these will be the coelom.

On the outer surface proceeding forwards from the Blastopore chink, two folds of the outer layer of cells arise in a manner not at all unlike that depicted diagrammatically on page 371. A view of these folds is shown (Fig. 255, 14). They are the *Neural Folds* and finally they will meet and fuse in the middle line to form a tube which develops into the brain and spinal cord of the embryo (Fig. 255, 15 and 16).

The position of the different structures at this stage is seen in Fig. 255, 15 and 16. Naturally in Fig. 255, 16, which is a median longitudinal section, the Mesoderm is not to be seen dorsally because the Notochord occupies the middle line—this is clearly indicated by Fig. 255, 15, the transverse section.

III

ANAEROBIC ORGANISMS

Most of the animal examples discussed in this book obtain their energy by the break-down, oxidation, of fats, carbohydrates and proteins. This is accompanied by certain well-known respiratory phenomena in which oxygen is taken up from the air or water and eventually the end products, carbon dioxide and water, are excreted. There are, however, certain organisms which hold their own in environments almost lacking in free oxygen. That such is possible is not surprising, for it has been shown (page 218) that the most powerful muscle contractions in the highest organisms are accomplished without initial oxidation—and that this oxidation follows *afterwards*, removing certain products of the primary chemical changes and providing energy for rebuilding essential substances for new contractions.

The Nematode worm, *Ascaris*, living as a parasite in the intestine, is obviously not in a position to carry on physiological processes in the manner of free living animals, and probably the same applies to most intestinal parasites, such as *Taenia* for another example.

In the case of *Ascaris*, most of the energy seems to be derived by a chemical splitting of carbohydrates—no oxidation being involved at all. Fat and proteins play an inconspicuous part in the supply of energy but remarkably large stores of carbohydrates are maintained, in particular glycogen. The products of the reactions involved are Carbon dioxide and more unusual substances, the fatty acids such as Butyric and Valerianic Acids.

Experiments seem to show, however, that some oxygen may possibly be obtained from the surrounding fluids, for *Ascaris* has been kept alive twice as long in salt solution when entrance of oxygen is permitted as when excluded. Further investigations of the physiology of most parasitic animals is badly needed however.

Certain well-known bacteria can only be cultivated in the absence of oxygen. The organism causing Tetanus (lock-jaw) is one of these. The energy requirements in these cases also seem to be dependent on the decomposition of carbohydrates (glucose for example).

All organisms of the kind referred to above are described as *Anaerobic* in contrast to the more usual Aerobic forms dependent on free oxygen, and normal respiratory processes. It is generally considered that an Anaerobic metabolism is an inefficient method of obtaining energy as compared with that of aerobic creatures. It is probable that the tapeworm and liver fluke present conditions similar to those discussed above for *Ascaris*.

IV

HYDROGEN ION CONCENTRATION

Not many years ago the above term would scarcely have been heard outside the advanced physical chemistry laboratory. Now it is almost a matter for an elementary text-book of biology. It is an expression which simply denotes with delicate precision the degree of alkalinity or degree of acidity of a medium. When a compound like common salt (NaCl) or caustic soda (NaOH) is dissolved in water, the molecules are to a certain extent ionised, and the solution contains sodium and chlorine ions as well as NaCl molecules, or sodium ions and hydroxyl (OH) ions in the case of caustic soda solutions. But even pure water is to a small degree ionised and contains a number of hydrogen ions and a number of hydroxyl ions.

$$H_2O \rightleftarrows H + OH.$$

The numbers of H and OH ions in this case are equal, and we say the fluid (pure water) is neutral. When a solution contains more hydroxyl ions than hydrogen ions it is said to be alkaline. When it contains a relative excess of hydrogen ions it is said to be acid.

The measurement of the hydrogen ion concentration is conveniently carried out by the use of certain indicators—litmus, methyl orange phenolphthalein, etc.—whose colours depend upon this factor. The concentration is usually denoted by a number and the sign p_H. Thus pure water has a p_H of 7. Solutions with a p_H less than 7 will be acid and those with a p_H more than 7 will be alkaline.

We have emphasised the importance of the hydrogen ion concentration to the biologists. It has long been known that certain Protozoa and other organisms would be found in one pond, but not in another, and the quality of the water and other differences in the environment have been put forward in a general way as the explanation. The hydrogen ion concentration is now known definitely to be one of the determining factors, and animal and plant life has been shown to be very susceptible to it. Indeed the proper growth of Amoeba in a laboratory culture depends upon the hydrogen ion concentration of the culture fluid. The proper functioning of the blood is also bound up with the condition of its hydrogen ion concentration.

Hydrogen ion indicators and standards can be procured from British Drug Houses, Ltd., London. It will be necessary to look up further details on the subject in order to use the indicators properly, but their use is really quite simple.

INDEX

Numbers in heavy type refer to pages with illustrations of the structure in question.

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